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Ries et al.

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(54) **ELECTRONICS ASSEMBLY FOR IMPLANTABLE MEDICAL DEVICE**

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(22) Filed: **Oct. 15, 2020**

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Related U.S. Application Data

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(51) **Int. Cl.**
A61N 1/375 (2006.01)

(52) **U.S. Cl.**
CPC *A61N 1/3754* (2013.01); *A61N 1/37512* (2017.08)

(58) **Field of Classification Search**
CPC A61N 1/3754; A61N 1/37512
See application file for complete search history.

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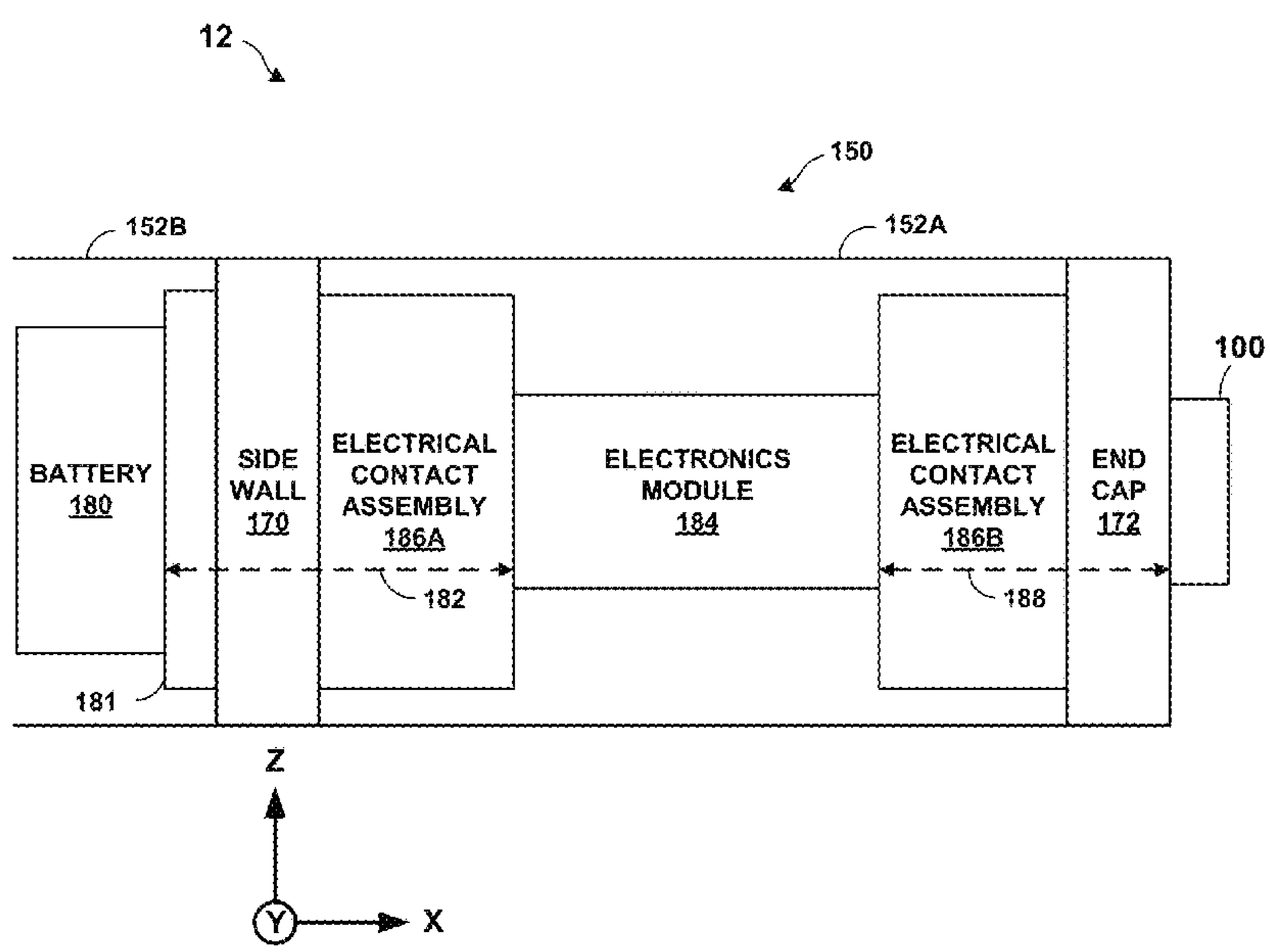
(57) **ABSTRACT**

In some examples, an implantable medical device includes a battery, an electronics module electrically connected to the battery, and an elongated housing comprising a side wall positioned between the battery and an end cap, wherein the electronics module is positioned within the elongated housing between the battery and the end cap. The implantable medical device also includes an electrical contact assembly comprising a first spring contact and a second spring contact. The electrical contact assembly of the implantable medical device is positioned within the elongated housing between the electronics module and the battery or the end cap.

15 Claims, 16 Drawing Sheets



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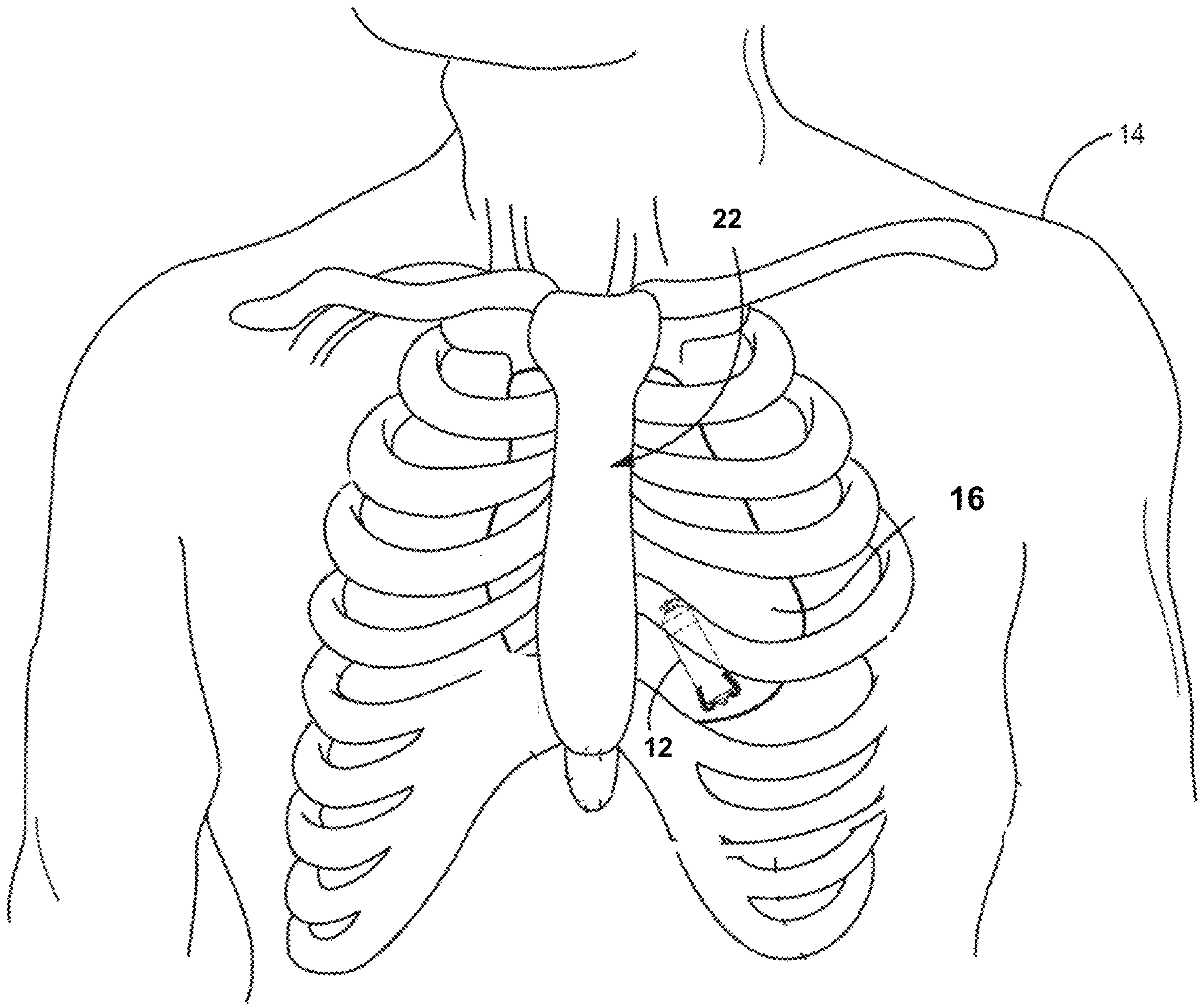

FIG. 1

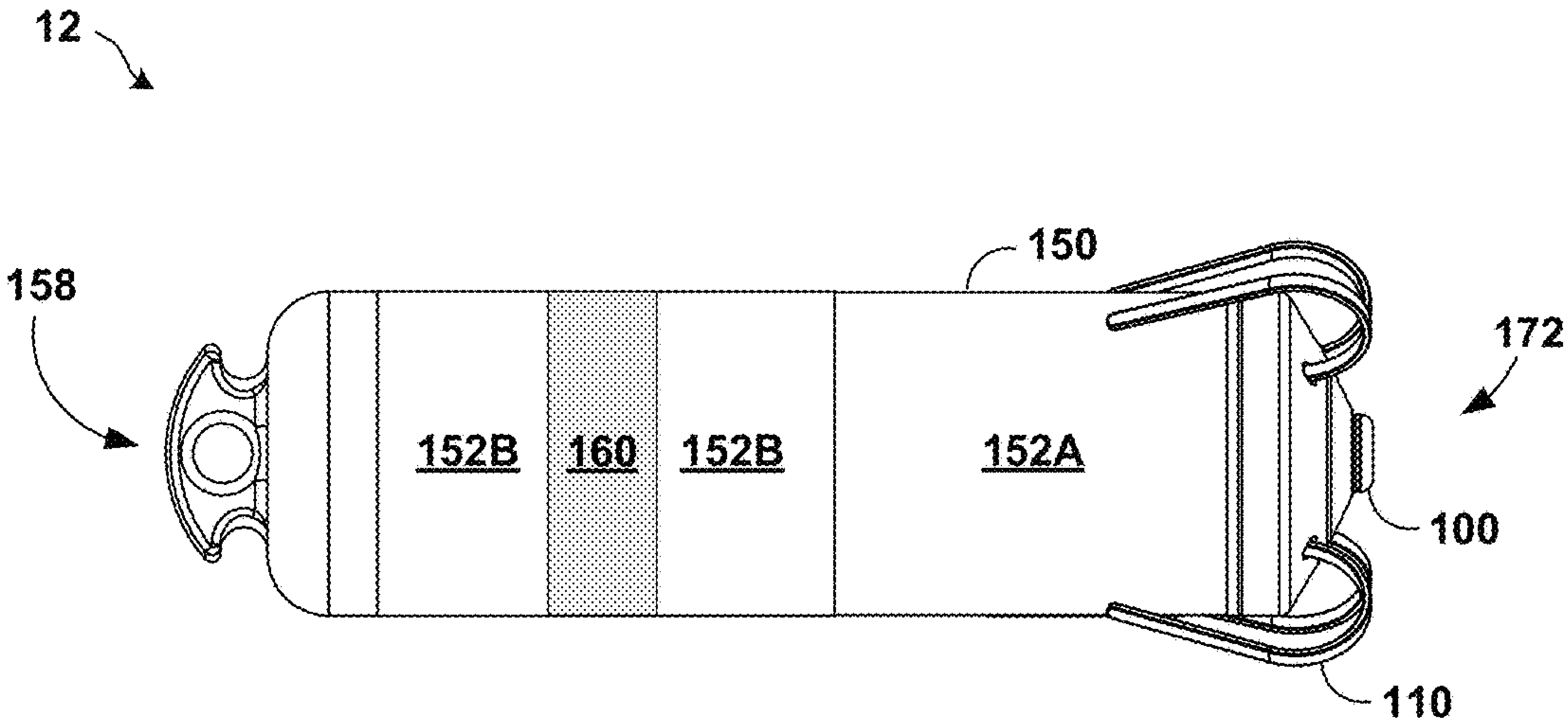
12
158
150
152B
160
152B
152A
172
100
110

FIG. 2

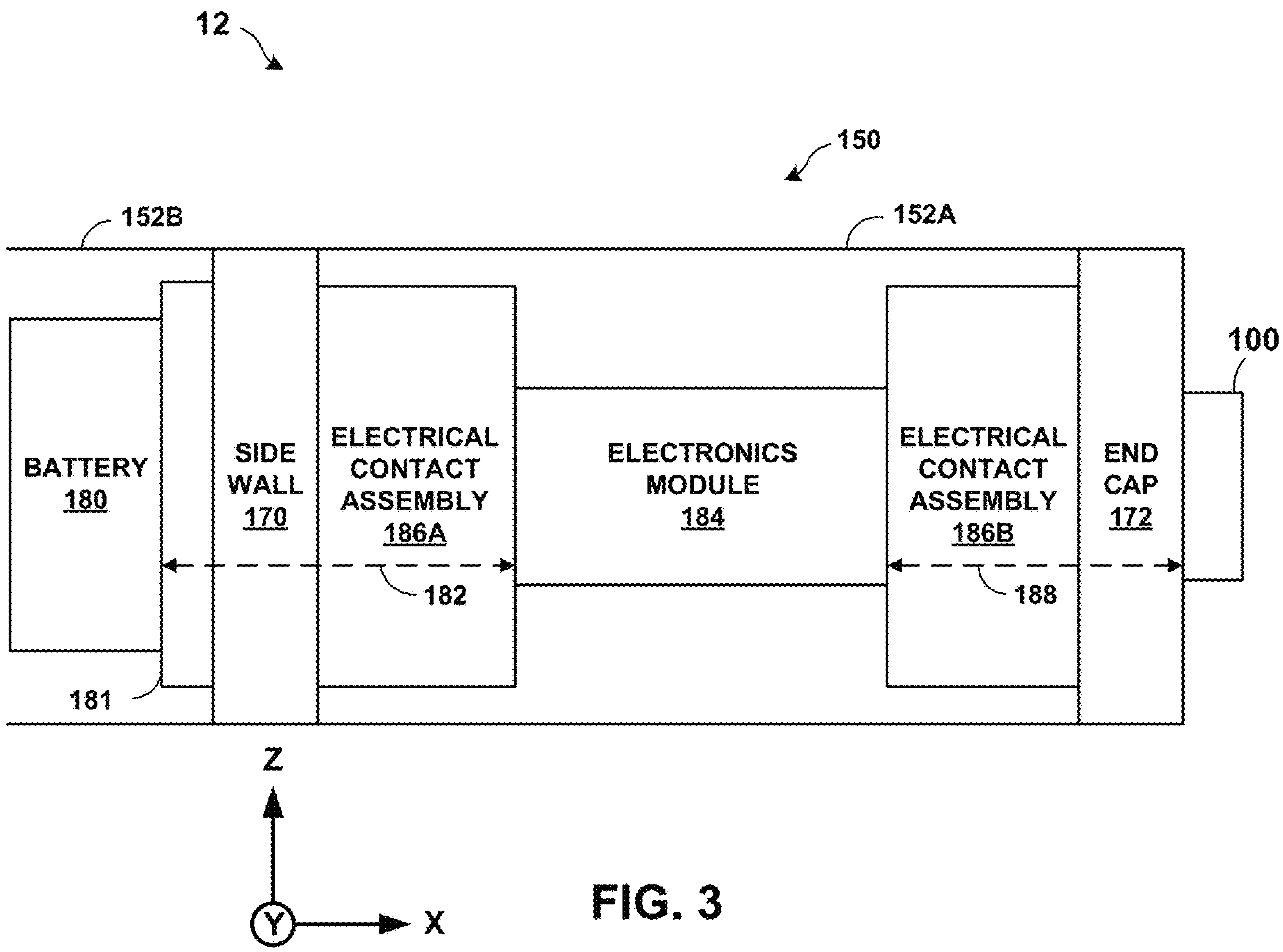
12
150
152B
152A
100
BATTERY
180
SIDE
WALL
170
ELECTRICAL
CONTACT
ASSEMBLY
186A
ELECTRONICS
MODULE
184
ELECTRICAL
CONTACT
ASSEMBLY
186B
END
CAP
172
182
188
181
Z
Y
X

FIG. 3

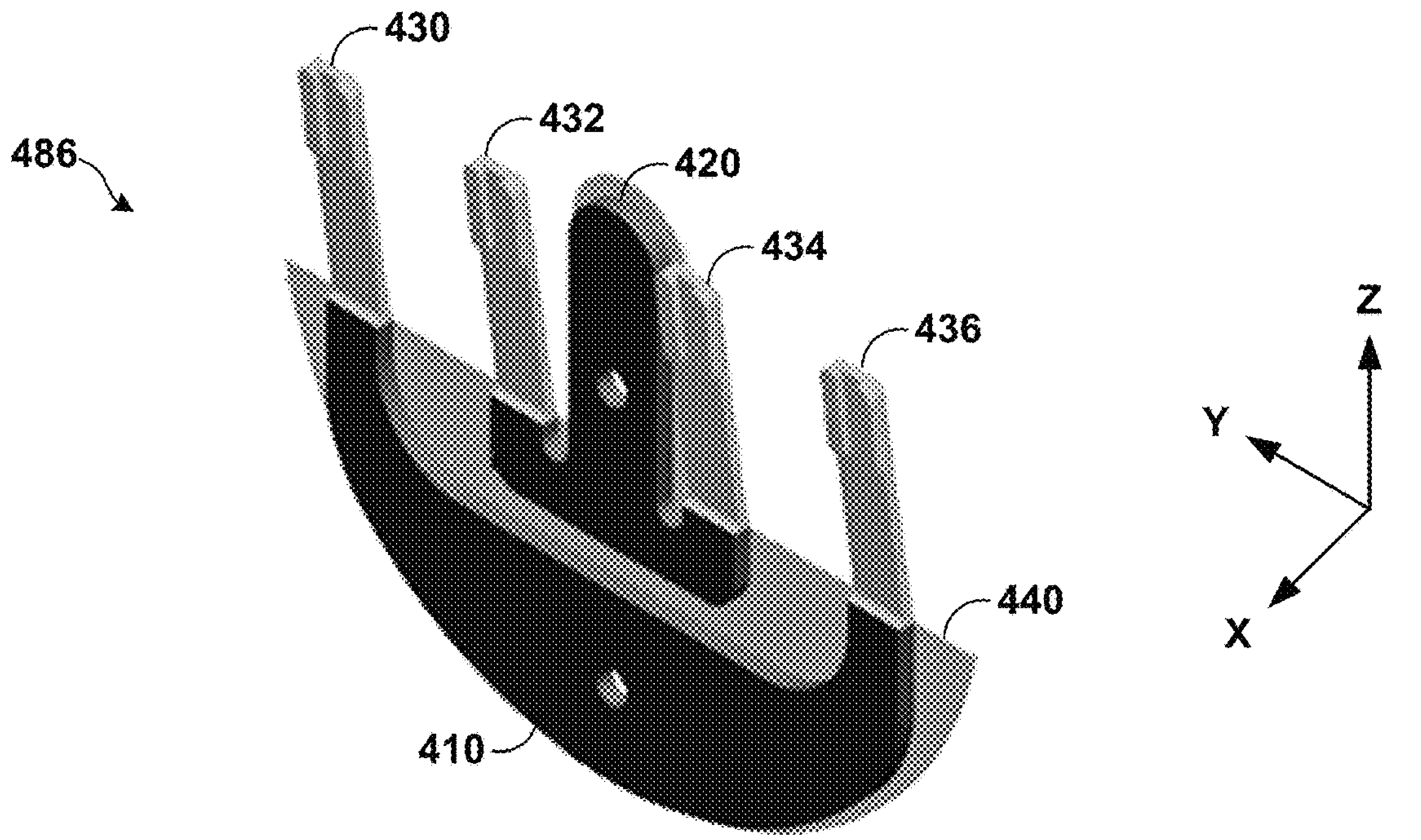

FIG. 4

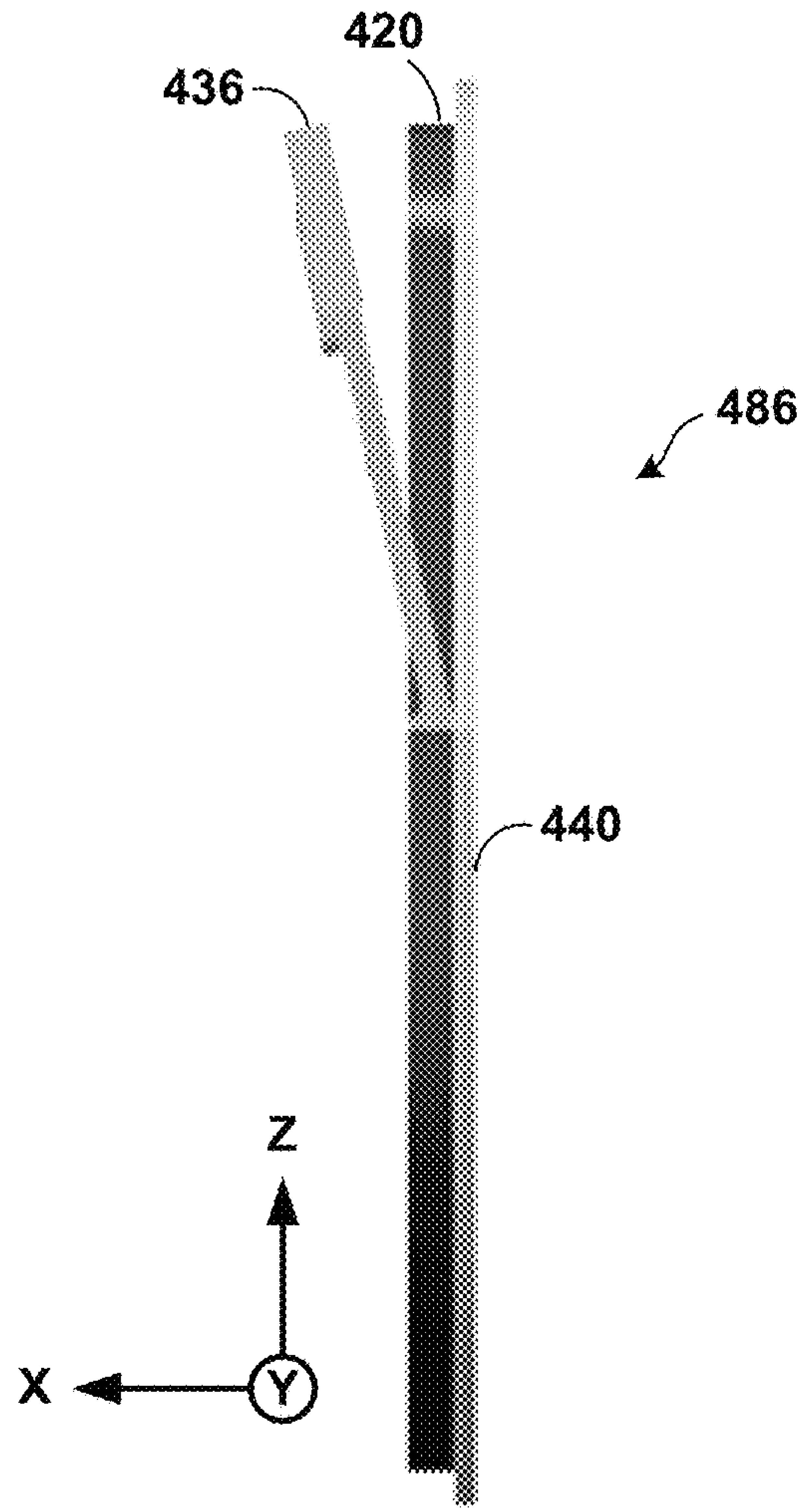

FIG. 5

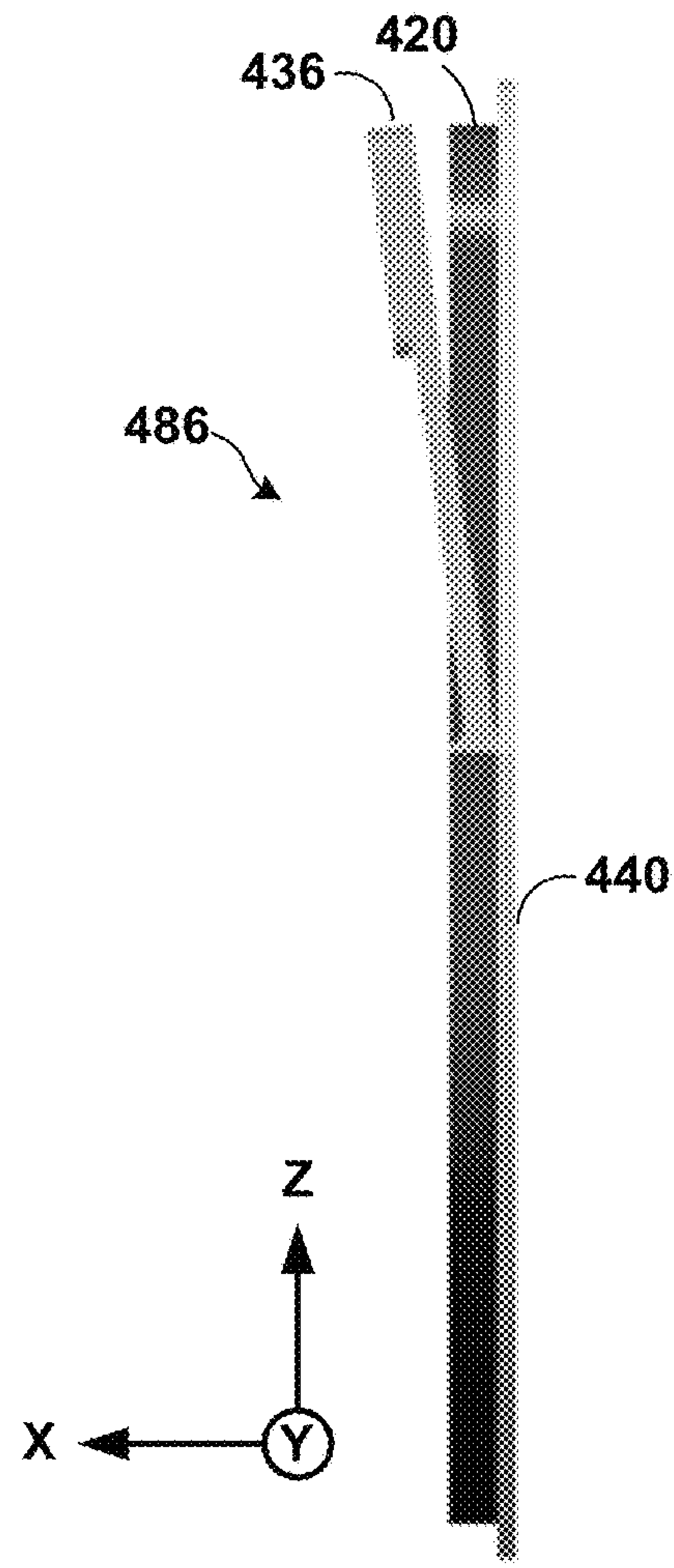

FIG. 6

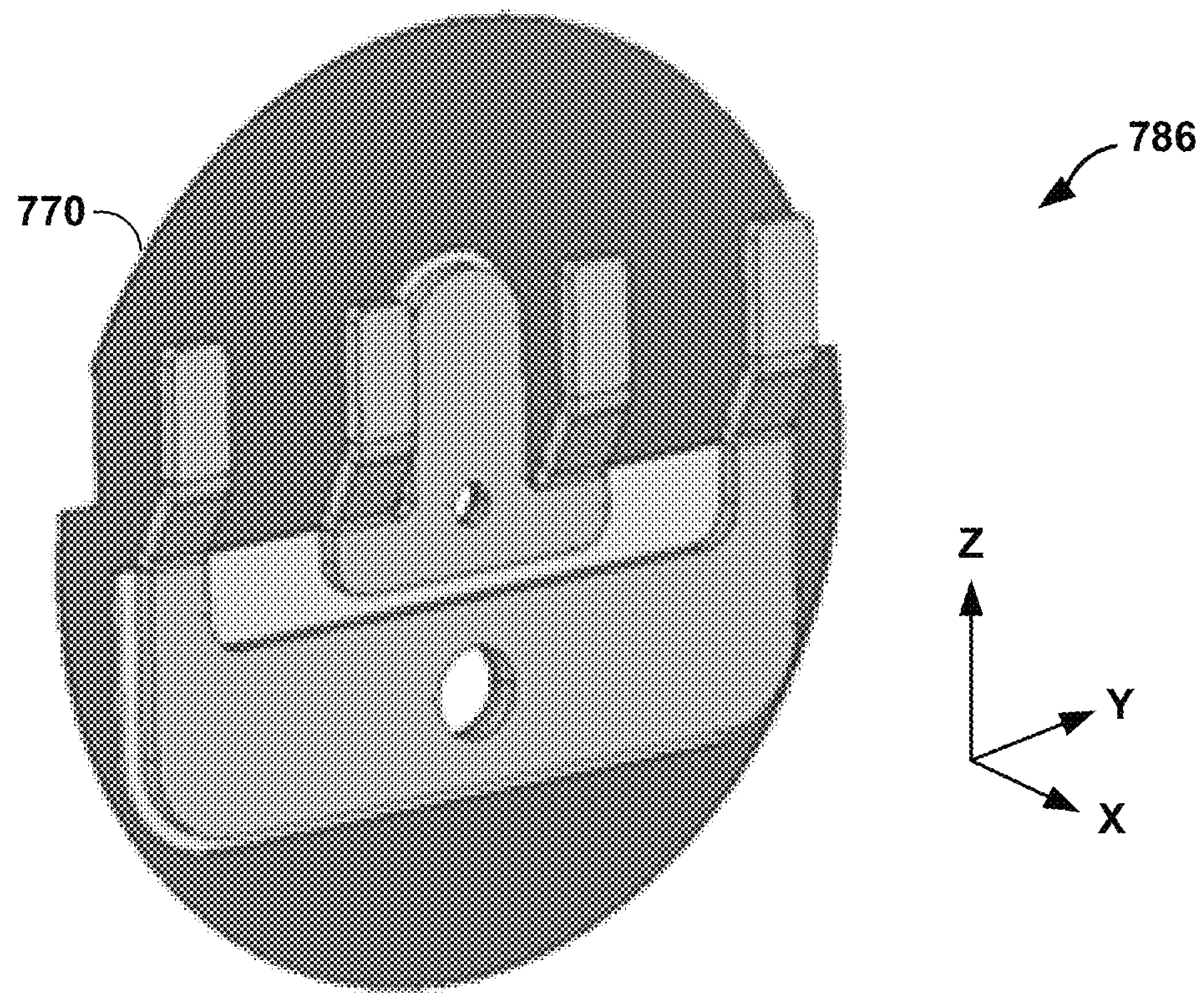

FIG. 7

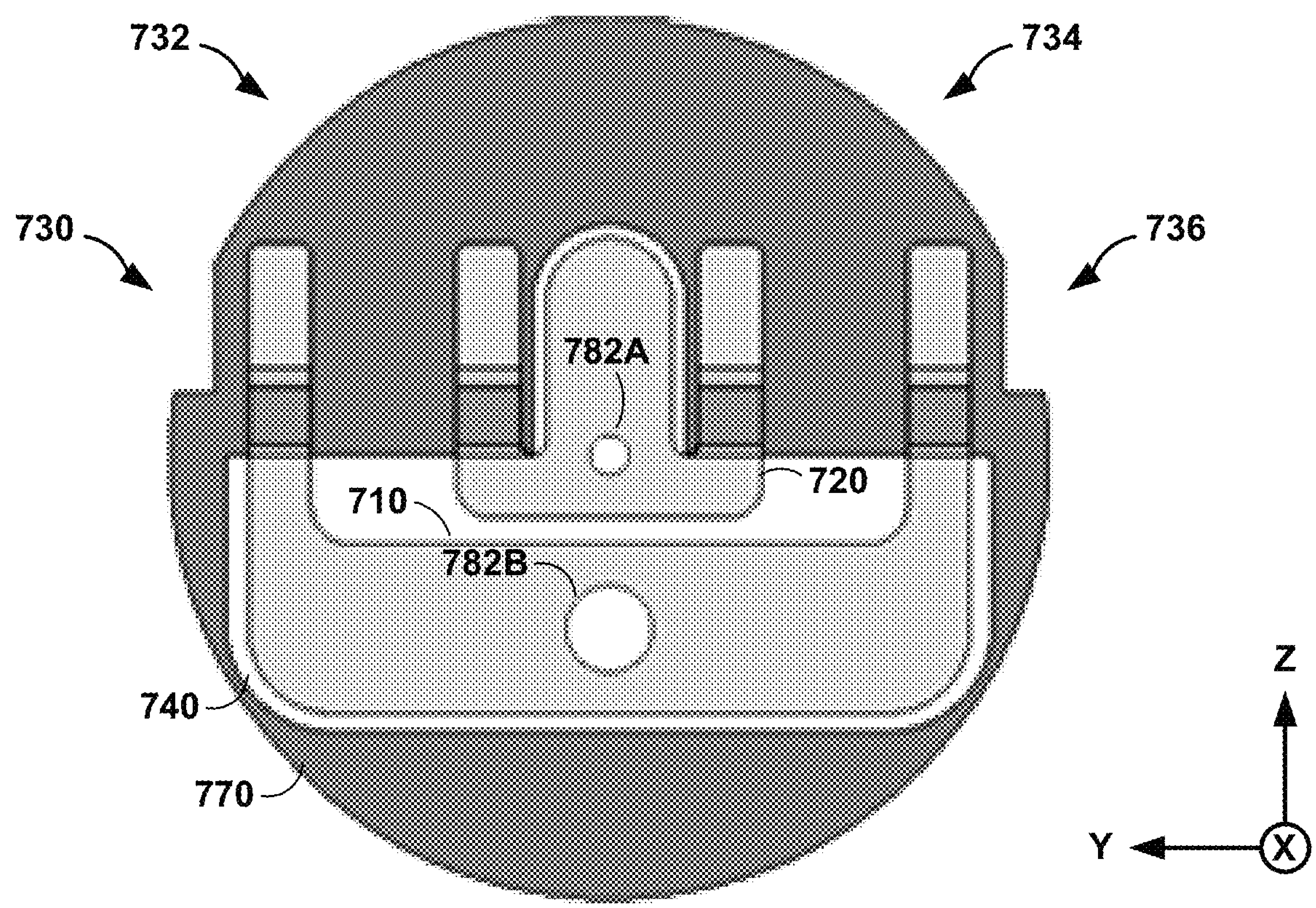

FIG. 8

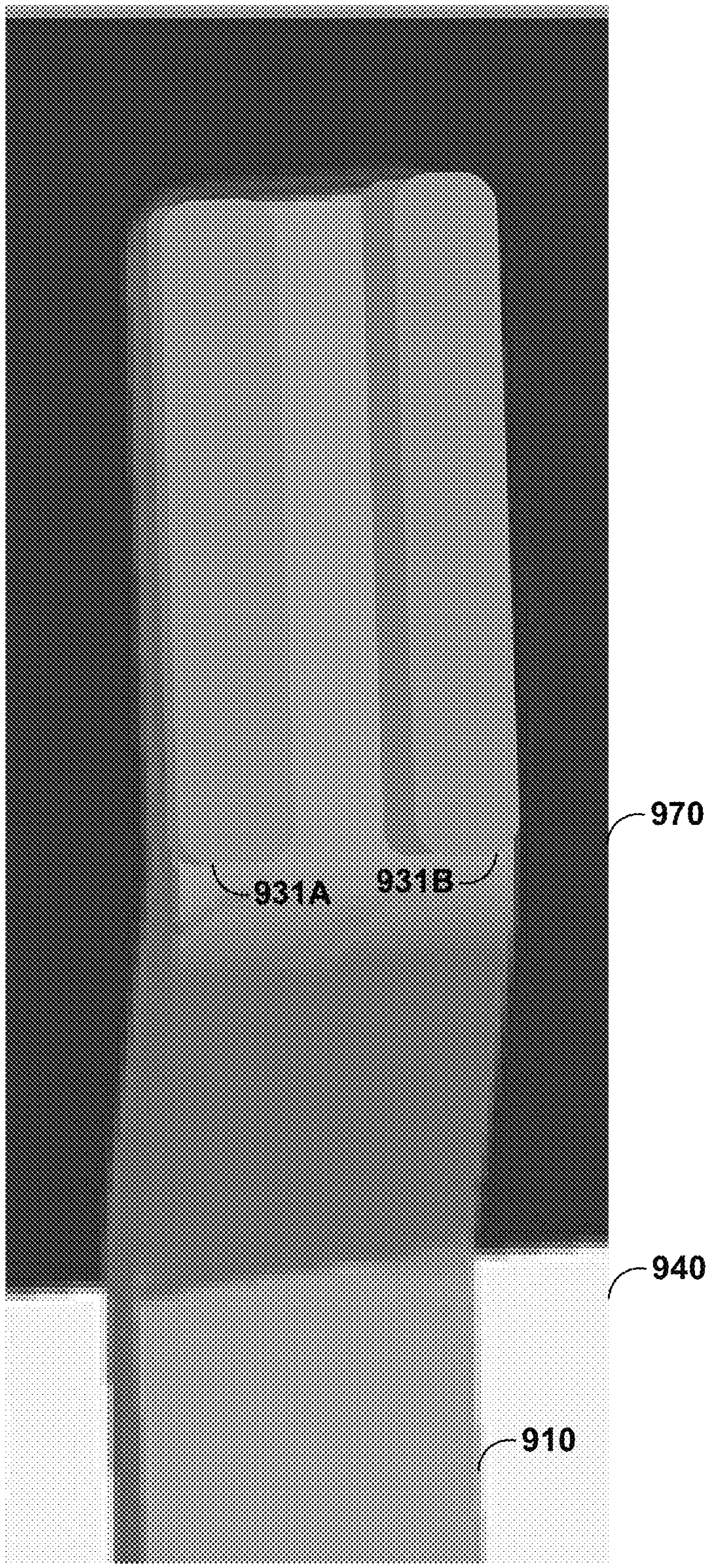

FIG. 9A

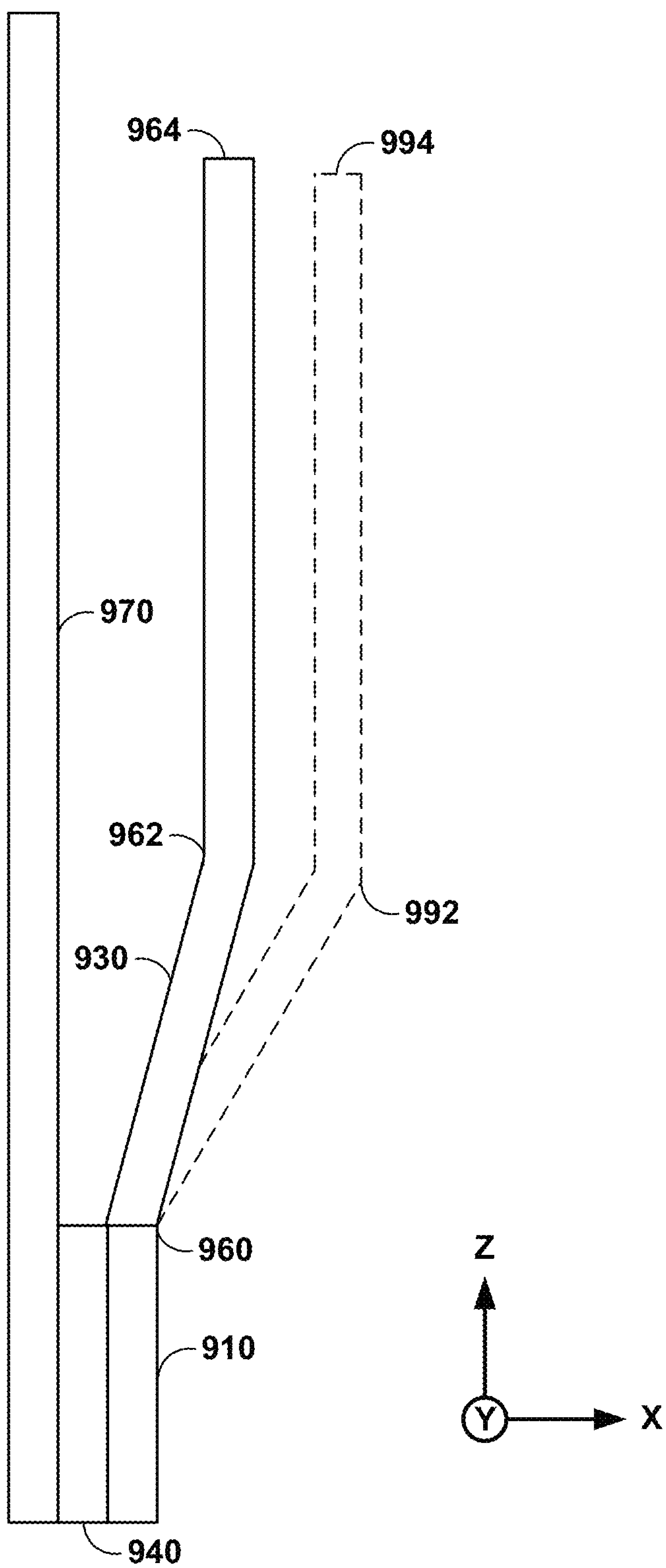

FIG. 9B

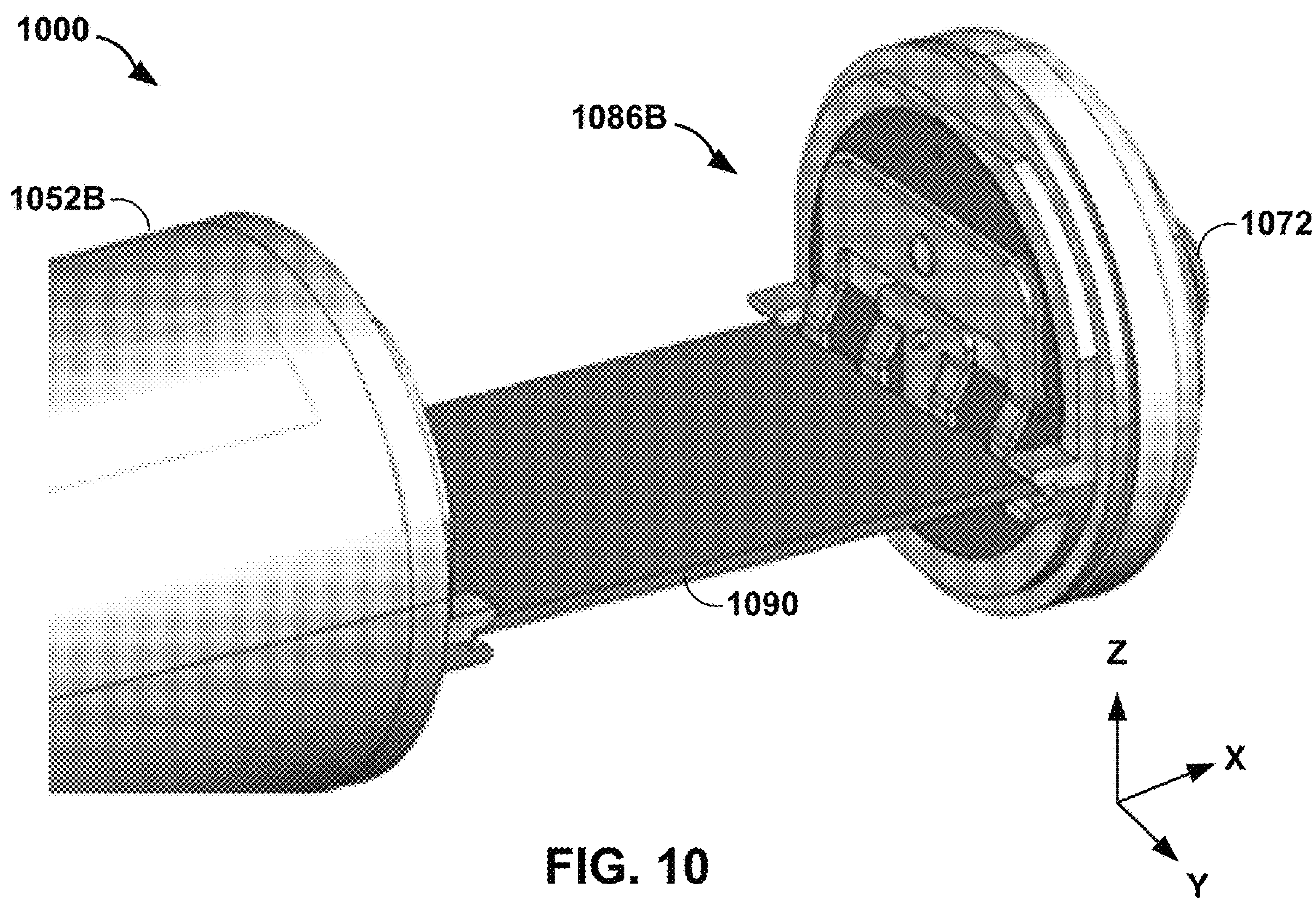

FIG. 10

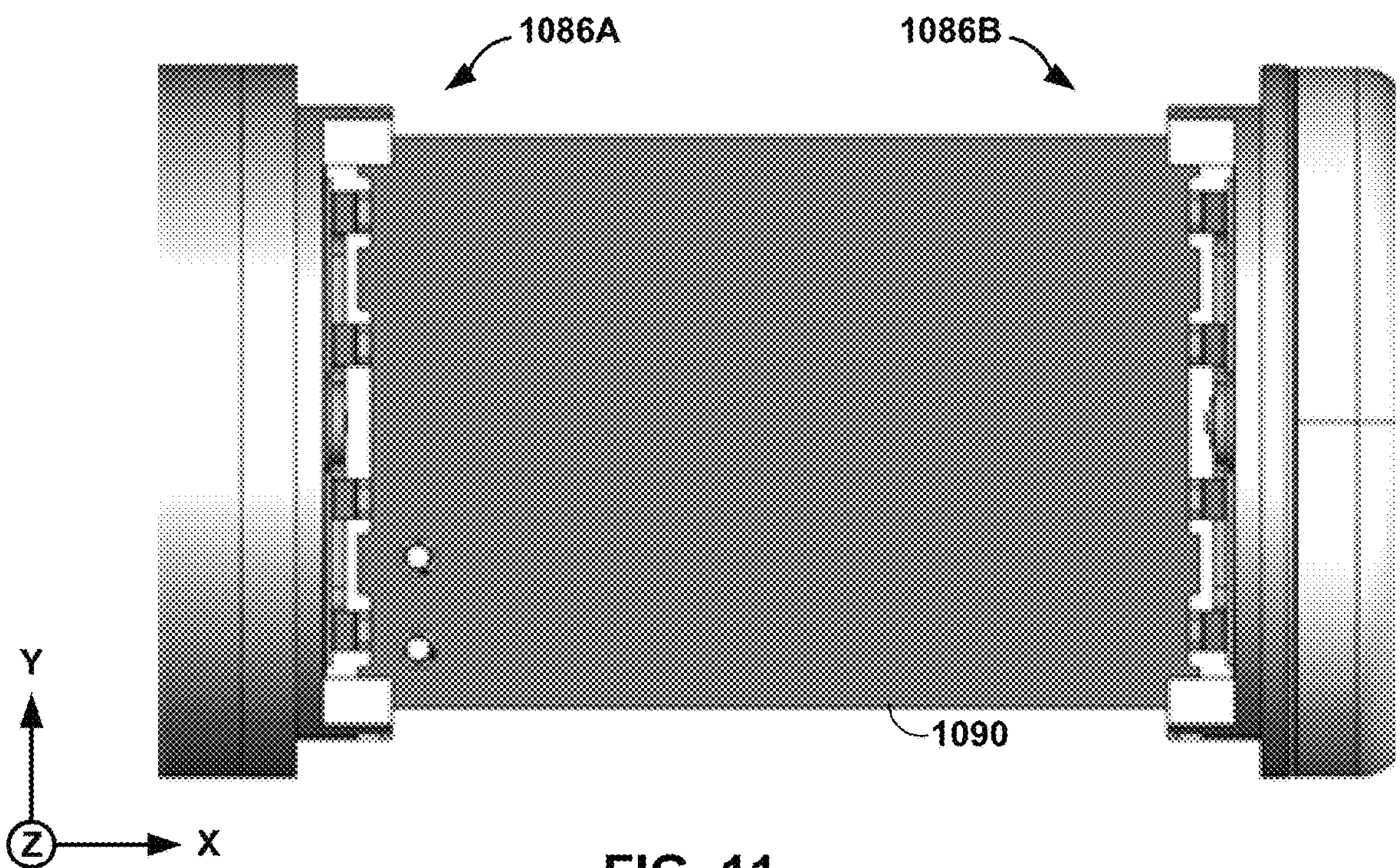

FIG. 11

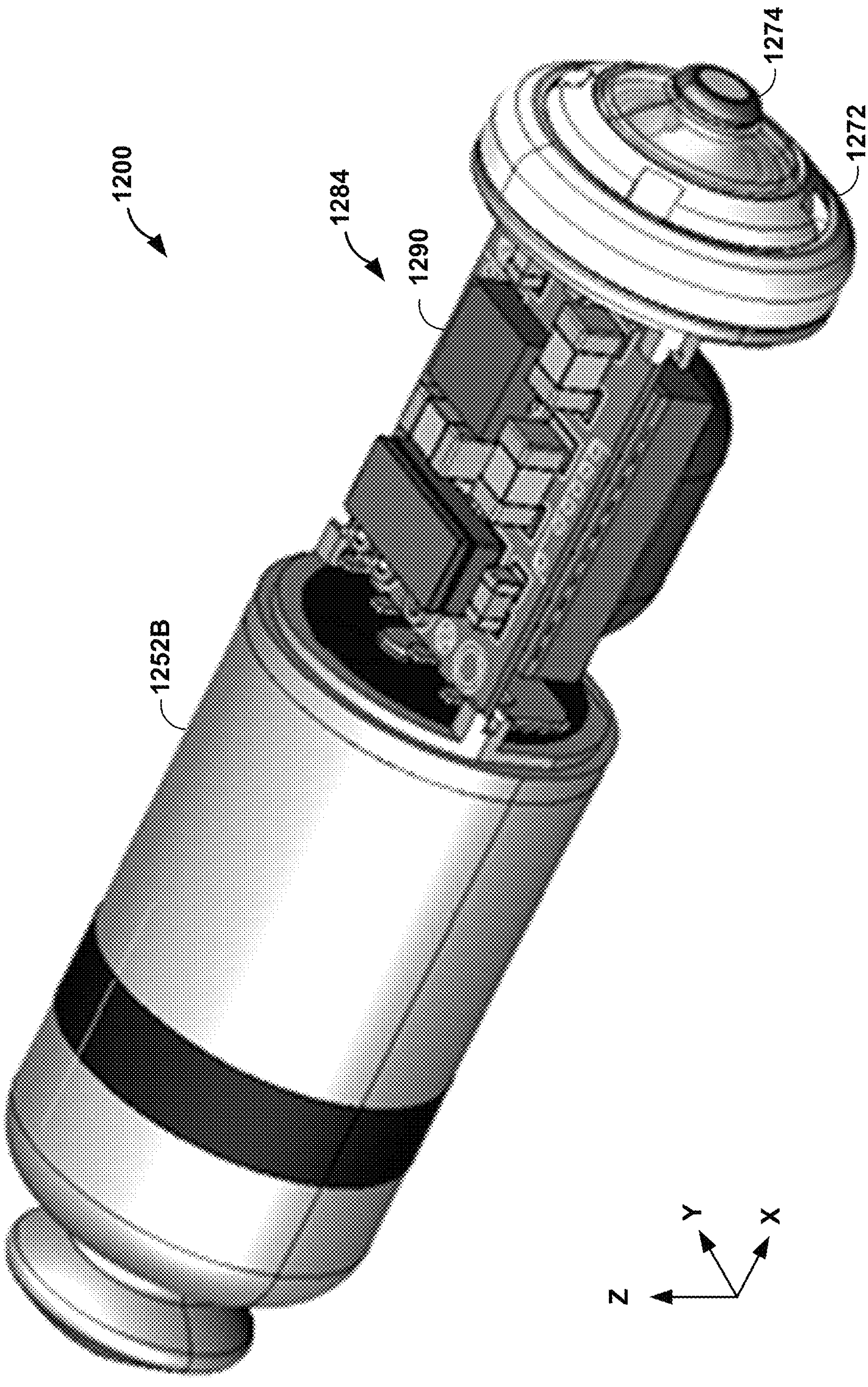

FIG. 12

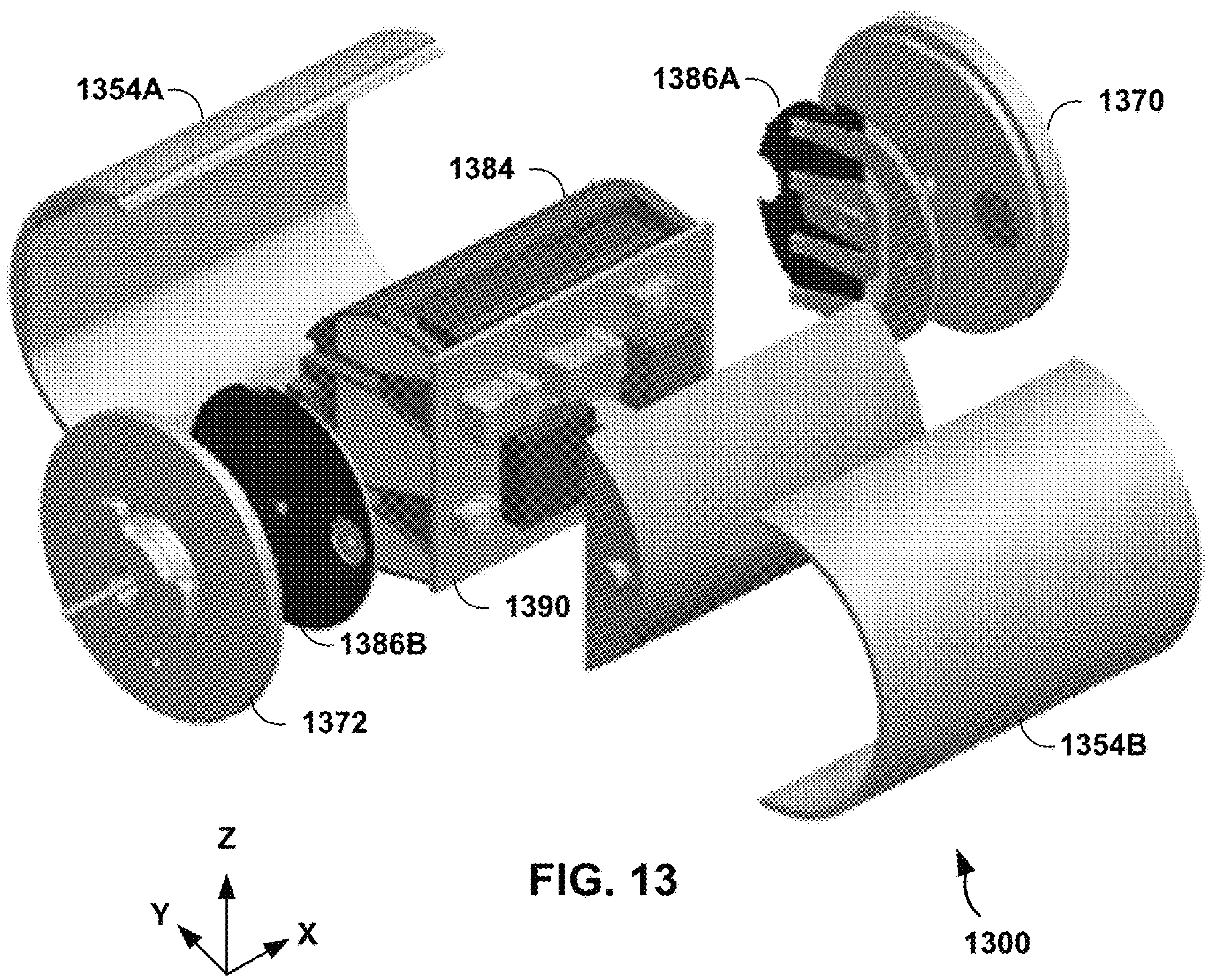
1354A
1386A
1370
1384
1390
1386B
1372
1354B
Z
Y
X
1300

FIG. 13

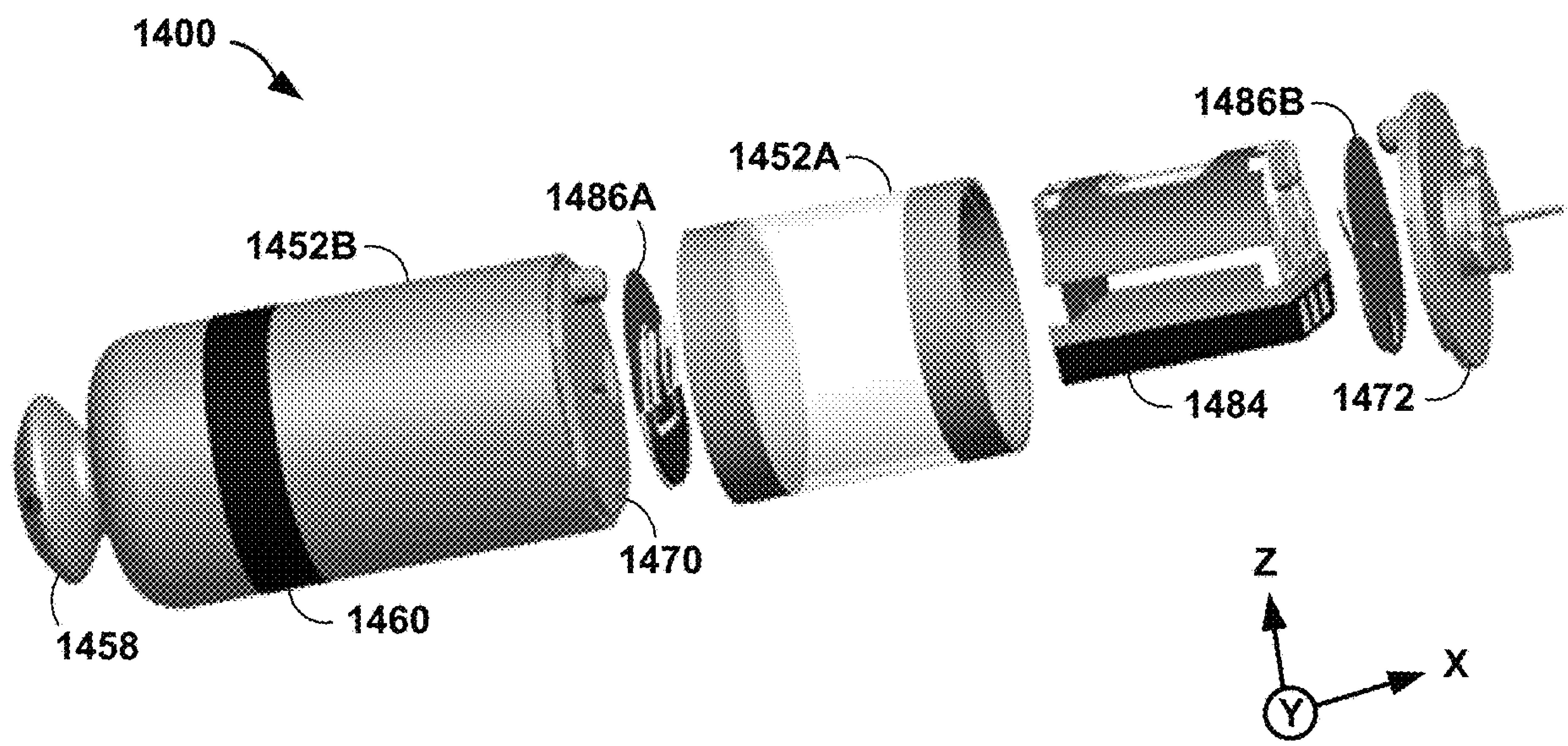
1400
1486B
1452A
1486A
1452B
1484
1472
1470
1460
1458
Z
X
Y

FIG. 14

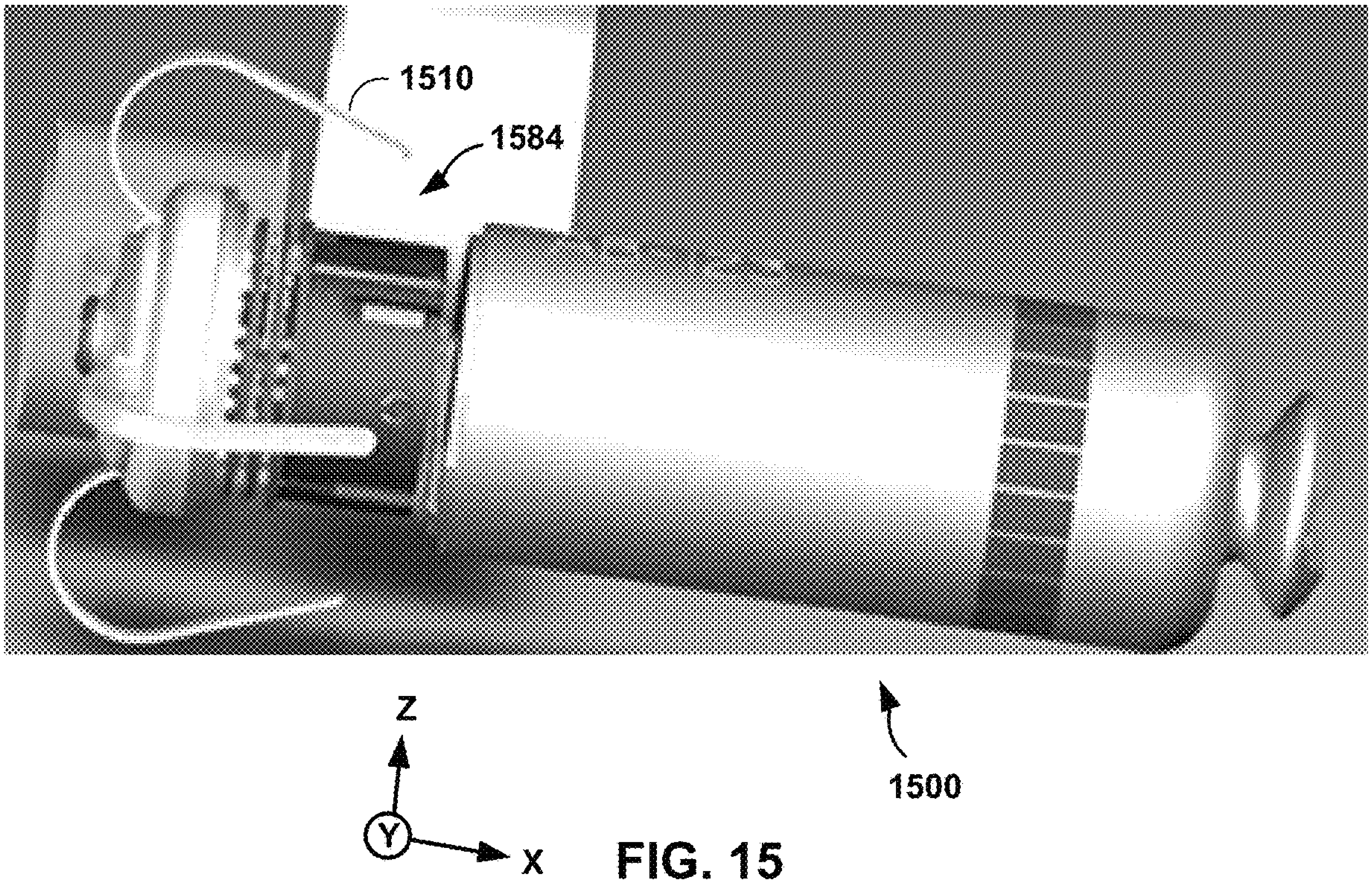

FIG. 15

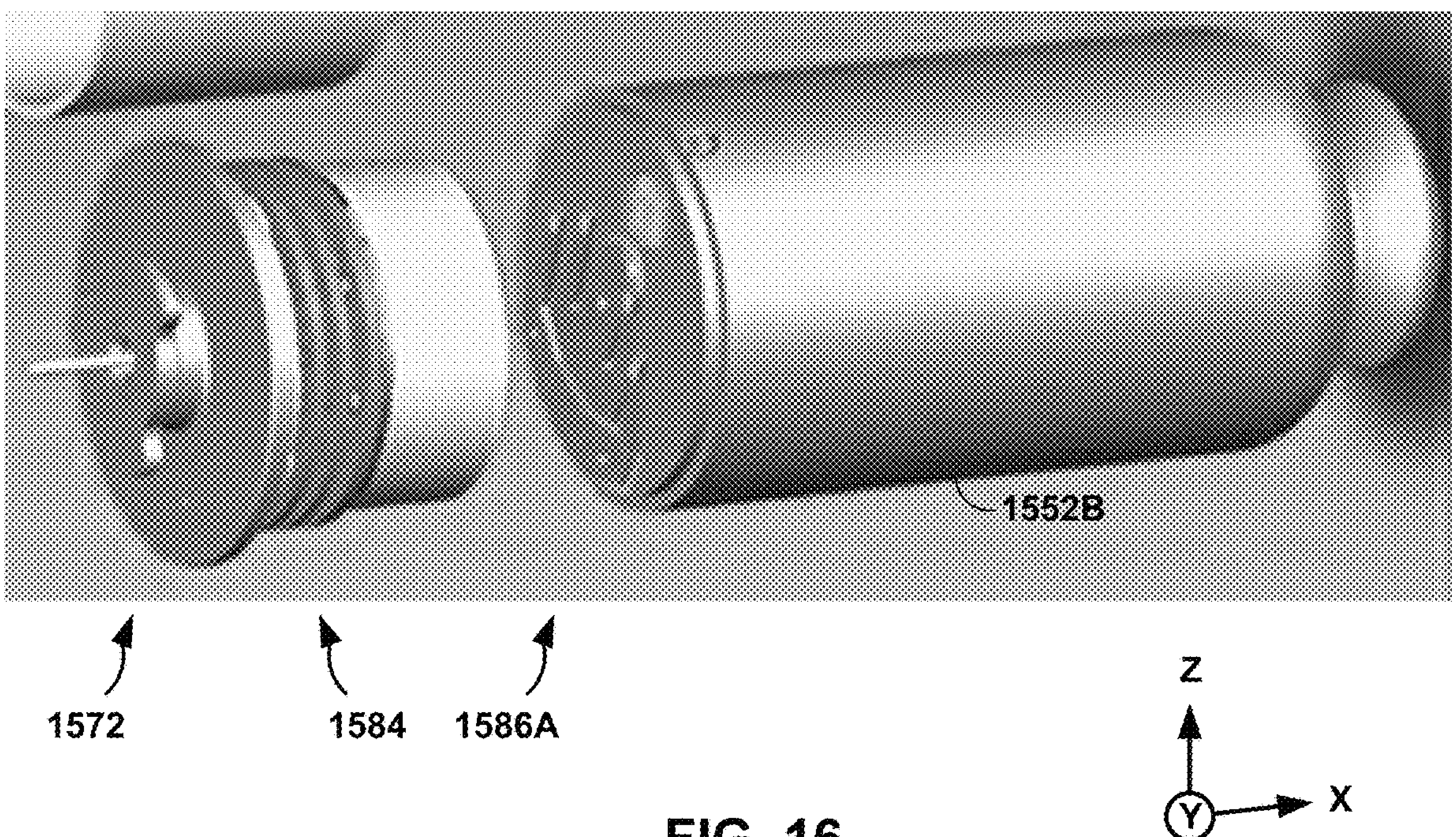

FIG. 16

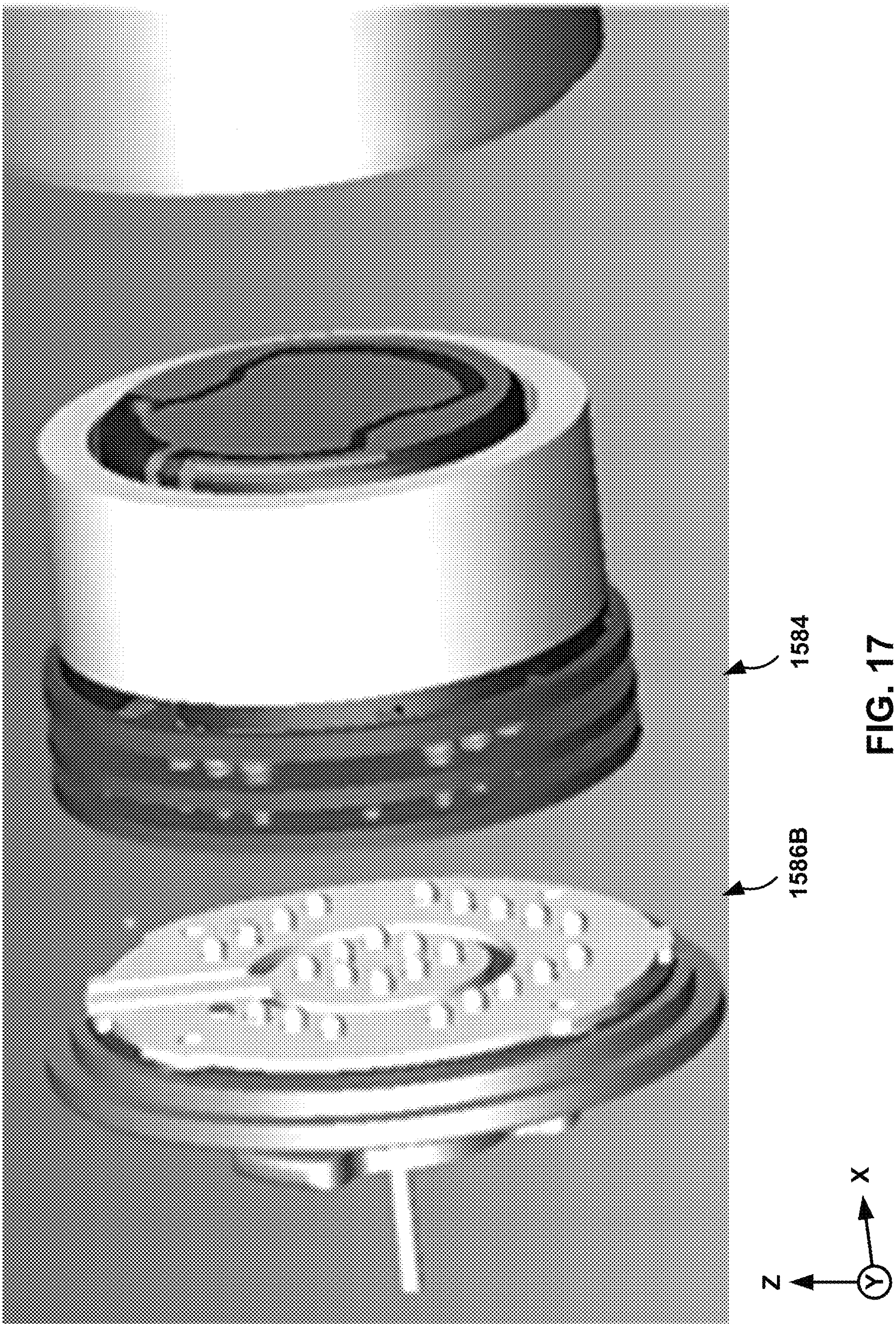

FIG. 17

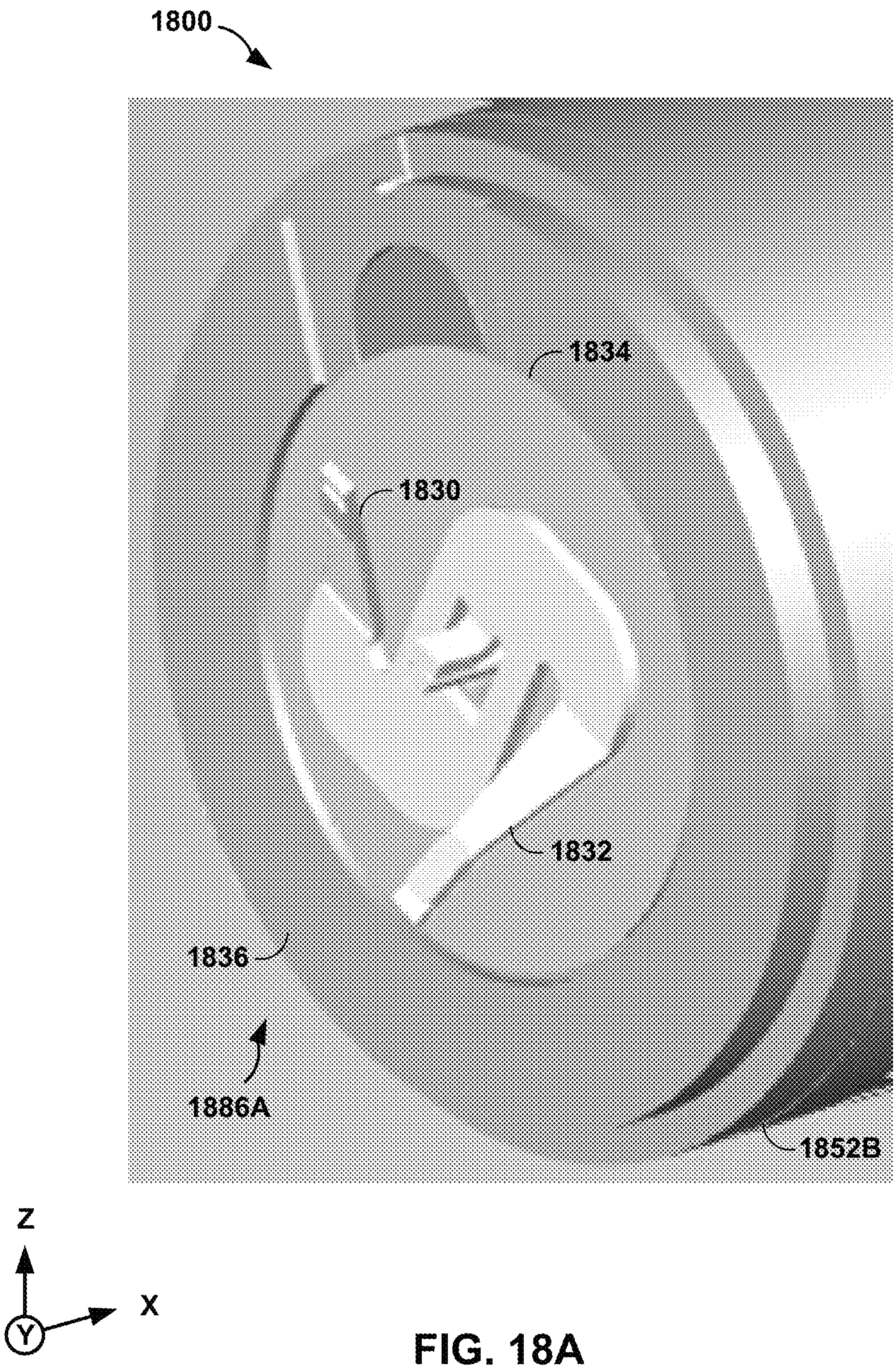

FIG. 18A

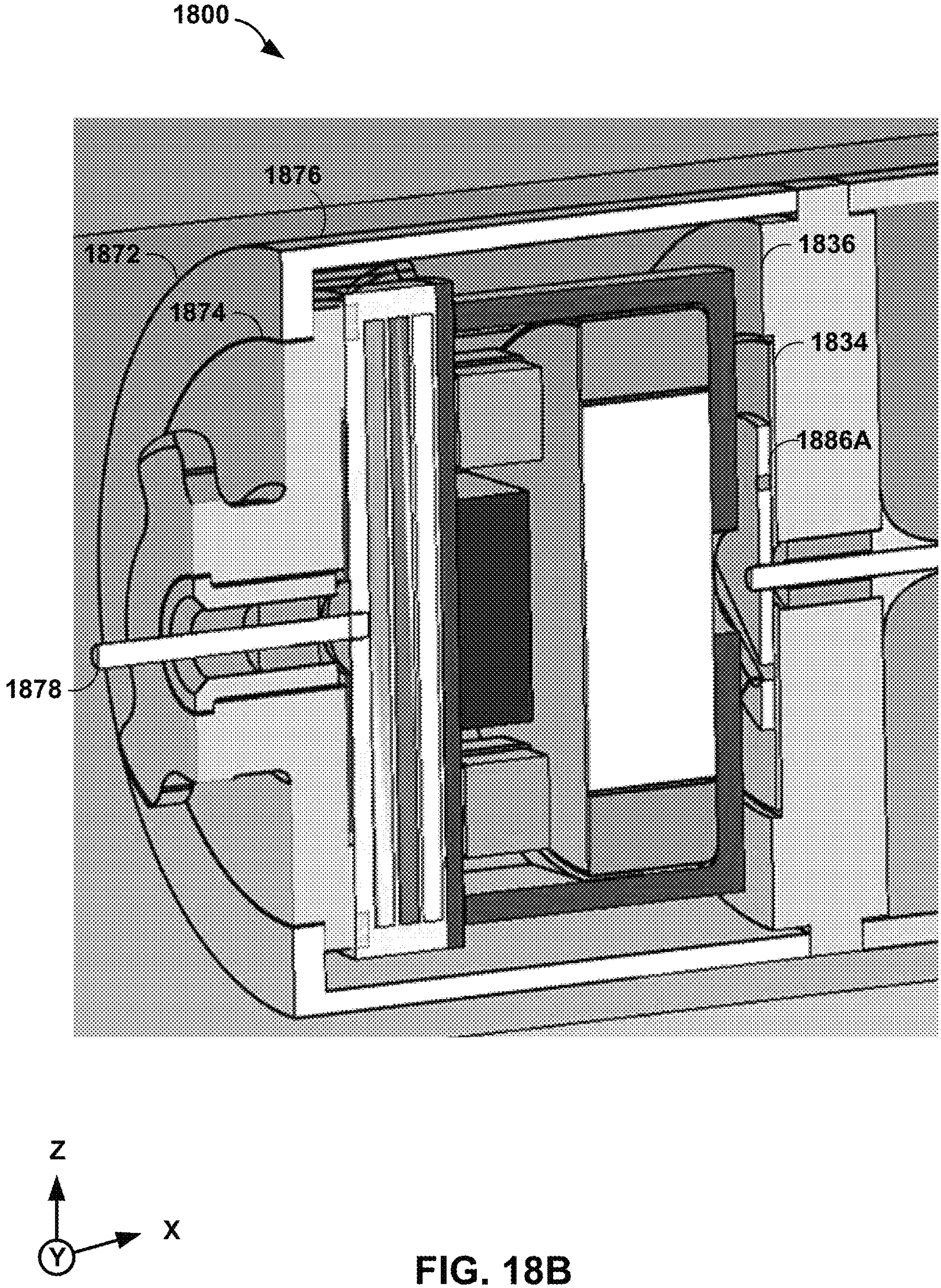

FIG. 18B

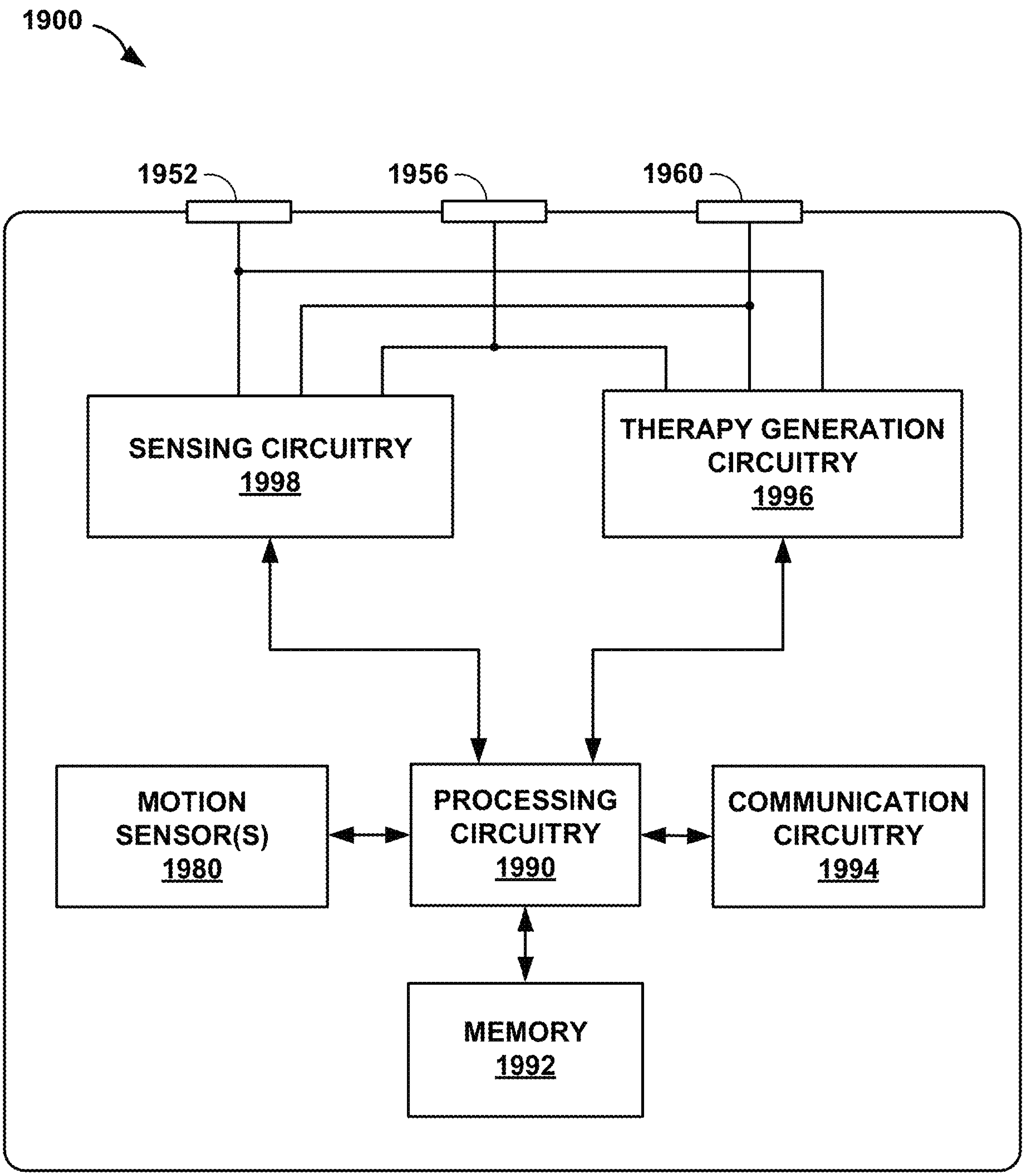
1900
1952
1956
1960
SENSING CIRCUITRY
1998
THERAPY GENERATION CIRCUITRY
1996
MOTION SENSOR(S)
1980
PROCESSING CIRCUITRY
1990
COMMUNICATION CIRCUITRY
1994
MEMORY
1992

FIG. 19

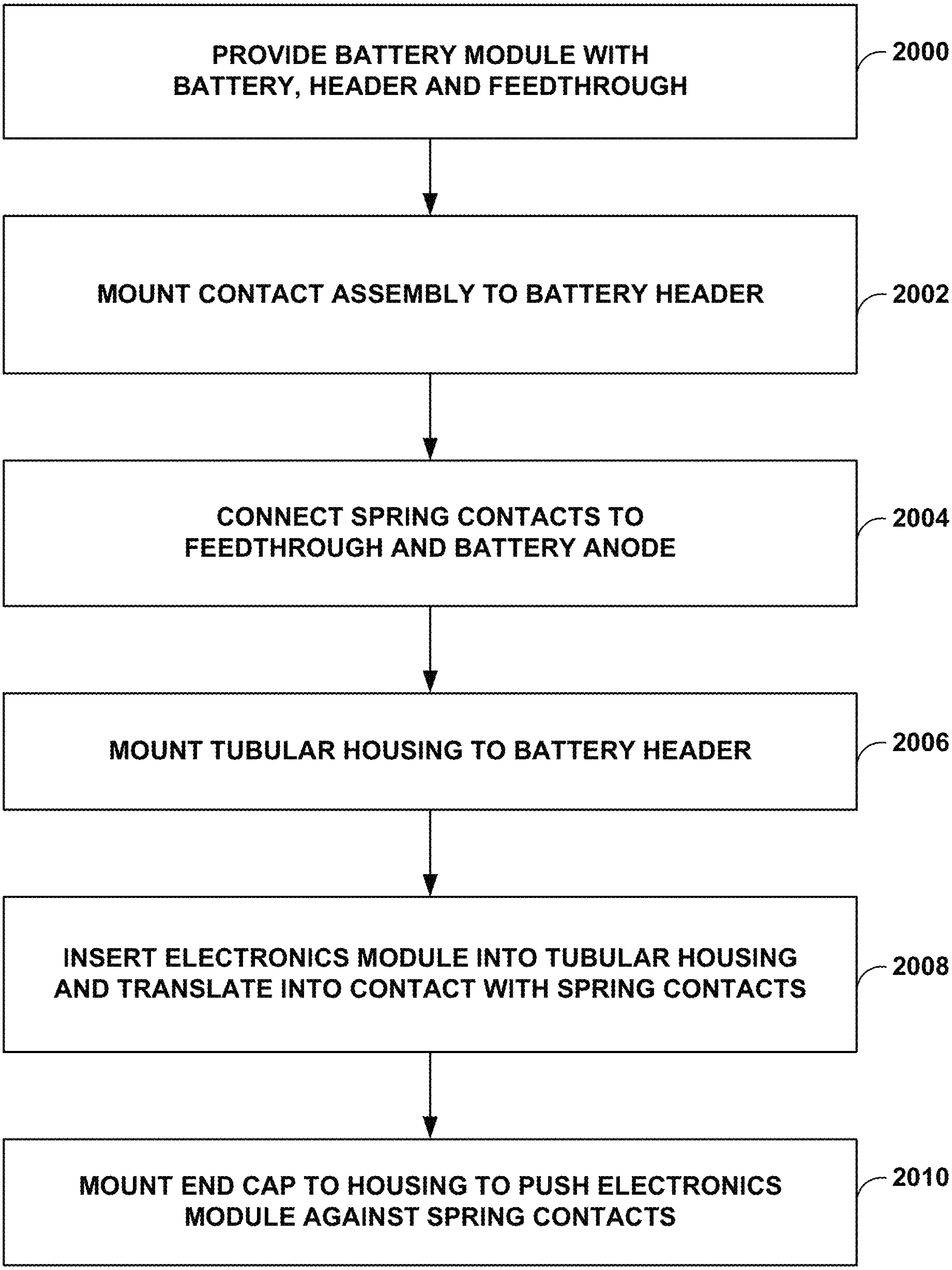
PROVIDE BATTERY MODULE WITH BATTERY, HEADER AND FEEDTHROUGH
2000
MOUNT CONTACT ASSEMBLY TO BATTERY HEADER
2002
CONNECT SPRING CONTACTS TO FEEDTHROUGH AND BATTERY ANODE
2004
MOUNT TUBULAR HOUSING TO BATTERY HEADER
2006
INSERT ELECTRONICS MODULE INTO TUBULAR HOUSING AND TRANSLATE INTO CONTACT WITH SPRING CONTACTS
2008
MOUNT END CAP TO HOUSING TO PUSH ELECTRONICS MODULE AGAINST SPRING CONTACTS
2010

FIG. 20

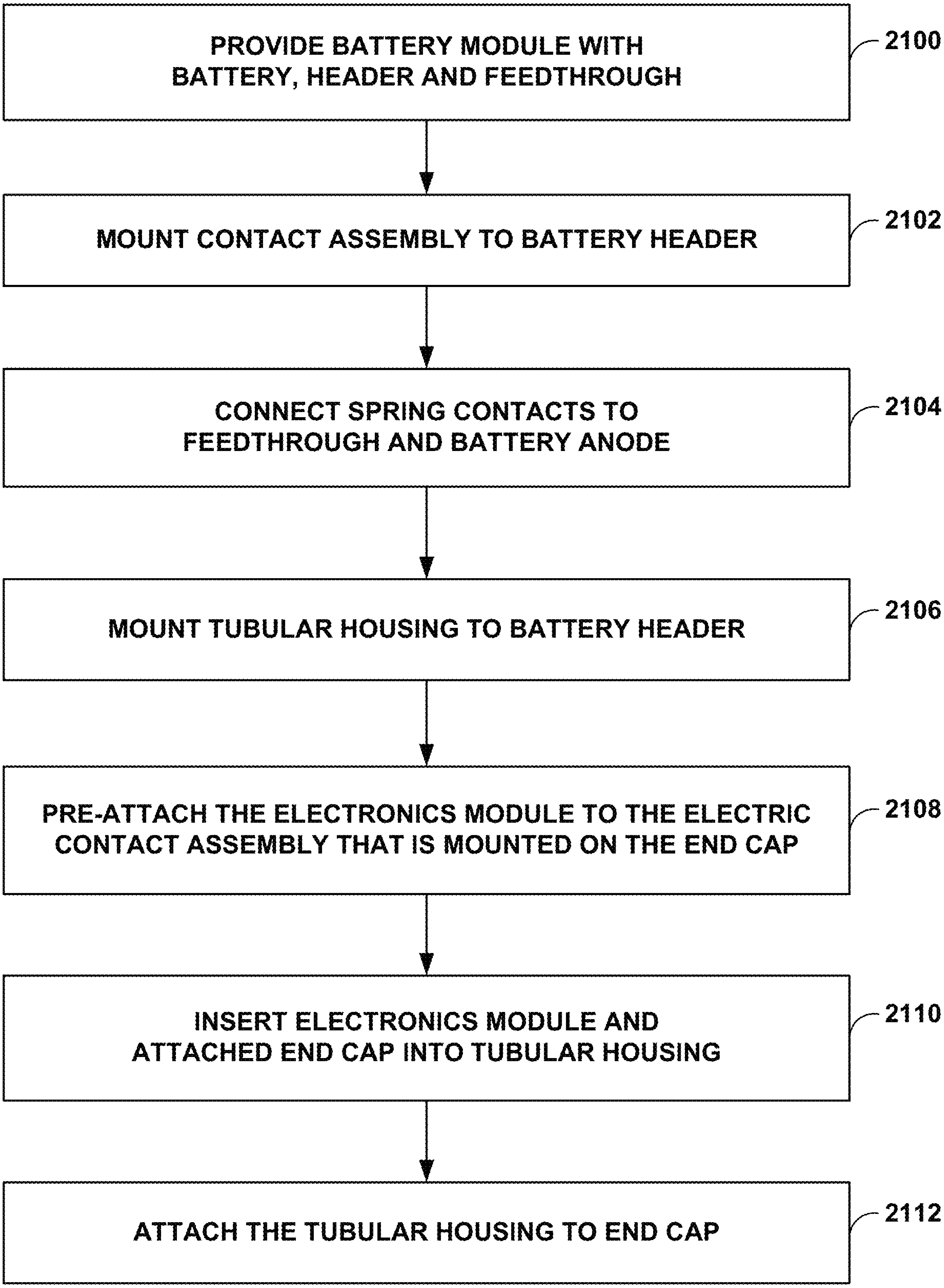
PROVIDE BATTERY MODULE WITH BATTERY, HEADER AND FEEDTHROUGH
2100
MOUNT CONTACT ASSEMBLY TO BATTERY HEADER
2102
CONNECT SPRING CONTACTS TO FEEDTHROUGH AND BATTERY ANODE
2104
MOUNT TUBULAR HOUSING TO BATTERY HEADER
2106
PRE-ATTACH THE ELECTRONICS MODULE TO THE ELECTRIC CONTACT ASSEMBLY THAT IS MOUNTED ON THE END CAP
2108
INSERT ELECTRONICS MODULE AND ATTACHED END CAP INTO TUBULAR HOUSING
2110
ATTACH THE TUBULAR HOUSING TO END CAP
2112

FIG. 21

ELECTRONICS ASSEMBLY FOR IMPLANTABLE MEDICAL DEVICE

This application claims the benefit of U.S. Provisional Patent Application 62/927,329, filed Oct. 29, 2019, the entire content of which is incorporated herein by reference.

TECHNICAL FIELD

The disclosure relates to medical devices, and more particularly to the structure and design of medical devices.

BACKGROUND

An implantable pacemaker may deliver pacing pulses to a patient's heart and monitor conditions of the patient's heart. In some examples, the implantable pacemaker comprises a pulse generator and one or more electrical leads. The pulse generator may, for example, be implanted in a small pocket in the patient's chest. The electrical leads may be coupled to the pulse generator, which may contain circuitry that generates pacing pulses and/or senses cardiac electrical activity. The electrical leads may extend from the pulse generator to a target site (e.g., an atrium and/or a ventricle) such that electrodes at the distal ends of the electrical leads are positioned at the target site. The pulse generator may provide electrical stimulation to the target site and/or monitor cardiac electrical activity at the target site via the electrodes.

Other implantable pacemakers are configured to be implanted entirely within a chamber of the heart. Such pacemakers may be referred to as intracardiac pacing devices or leadless pacing devices, and may include one or more electrodes on their outer housings to deliver therapeutic electrical signals and/or sense intrinsic depolarizations of the heart. Such pacemakers may be positioned within or outside of the heart and, in some examples, may be anchored to a wall of the heart via a fixation mechanism.

SUMMARY

In general, this disclosure is directed to techniques for an implantable medical device including a battery, an electronics module, and an electrical contact assembly configured to hold and connect the electronics module in place. The electrical contact assembly includes at least two spring contacts for connecting to the electronics module. The battery, electronics module, and electrical contact assembly are arranged in an elongated housing that includes an enclosing side wall and an end cap. The arrangement of the components within the housing according to the techniques of this disclosure can result in a less complex and less expensive manufacturing process than other arrangements.

In one example, an implantable medical device includes a battery, an electronics module electrically connected to the battery, and an elongated housing comprising a side wall extending between the battery and an end cap. The electronics module is positioned within the elongated housing between the battery and the end cap. The implantable medical device also includes an electrical contact assembly comprising a first spring contact and a second spring contact. The electrical contact assembly is positioned within the elongated housing between the electronics module and the battery or is positioned within the elongated housing between the electronics module and the end cap.

Another example is an implantable medical device including a battery, a battery header, and a first feedthrough

electrically connected to a first pole of the battery. The first feedthrough extends through the battery header. The implantable medical device also includes an elongated housing comprising a side wall extending between the battery header and an end cap. The implantable medical device further includes an electrical contact assembly mounted to the battery header and comprising a first spring contact and a second spring contact. The first spring contact is electrically connected to the first feedthrough. The implantable medical device includes an electronics module positioned within the housing between the battery header and the end cap. The electronics module is pressed against the first and second spring contacts of the electrical contact assembly, whereby the electronics module is electrically connected to the battery.

Other examples include an implantable medical device includes a battery, a battery header, and a feedthrough electrically connected to a cathode of the battery and extending through the battery header. The implantable medical device also includes an elongated tubular housing extending between a first end and a second end, wherein the first end is fixed to the battery header. The implantable medical device further includes an electronics header assembly comprising an end cap and an electronics module supported by the end cap. The implantable medical device includes an electrical contact assembly comprising a first spring contact and a second spring contact. The end cap of the electronics header assembly is fixed to the second end of the tubular housing. The electrical contact assembly is positioned within the tubular housing between the electronics module and the battery header. The first spring contact provides an electrical connection between the electronics module and battery cathode, and the elongated tubular housing provides an electrical connection between the electronics module and the battery anode.

Other examples include a method for assembling an implantable medical device. The method includes providing a battery module comprising a battery, a battery header, and a feedthrough electrically connected to a cathode of the battery and extending through the battery header. The method also includes mounting an electrical contact assembly to the battery header, the electrical contact assembly comprising a first spring contact and a second spring contact. The method further includes electrically connecting the first spring contact to the feedthrough. The method includes mounting an elongated tubular housing to the battery header about the electrical contact assembly, electrically connecting the elongated tubular housing to an anode of the battery, and inserting an electronics module into an open end of the tubular housing and translating the electronics module through the tubular housing into contact with the first and second spring contacts of the electrical contact assembly. The method also includes mounting an end cap to the open end of the tubular housing, whereby the electronics module is pushed against the first and second spring contacts, whereby the first and second spring contacts flex toward the battery header.

This summary is intended to provide an overview of the subject matter described in this disclosure. It is not intended to provide an exclusive or exhaustive explanation of the methods and systems described in detail within the accompanying drawings and description below. The details of one or more aspects of the disclosure are set forth in the accompanying drawings and the description below.

BRIEF DESCRIPTION OF DRAWINGS

The details of one or more examples of this disclosure are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of this disclosure will be apparent from the description and drawings, and from the claims.

FIG. **1** is a conceptual diagram illustrating an example cardiac medical device system implanted within a patient.

FIG. **2** is a conceptual illustration of an example configuration of a pacing device.

FIG. **3** is a block diagram of an implantable medical device including a battery, an electronics module, and an electrical contact assembly.

FIGS. **4-6** are diagrams of example electric contact assemblies, in accordance with one or more aspects of this disclosure.

FIGS. **7** and **8** are diagrams of an example electric contact assembly attached to an insulative backing, in accordance with one or more aspects of this disclosure.

FIGS. **9**A and **9**B are diagrams of an example spring contact of an electric contact assembly, in accordance with one or more aspects of this disclosure.

FIGS. **10** and **11** are diagrams of an example implantable medical device including the circuit board of an electronics module, in accordance with one or more aspects of this disclosure.

FIG. **12** is a diagram of an example implantable medical device including an electronics module with electronics components mounted on a circuit board, in accordance with one or more aspects of this disclosure.

FIGS. **13** and **14** are exploded view diagrams of two example implantable medical devices, in accordance with one or more aspects of this disclosure.

FIGS. **15-17** are exploded view diagrams of an example implantable medical device, in accordance with one or more aspects of this disclosure.

FIG. **18**A is a diagram of an example implantable medical device including an electric contact assembly with two spring fingers, in accordance with one or more aspects of this disclosure.

FIG. **18**B is a cut-away diagram of an example implantable medical device including an end cap and a feedthrough header, in accordance with one or more aspects of this disclosure.

FIG. **19** is a conceptual block diagram of an example implantable medical device, in accordance with one or more aspects of this disclosure.

FIG. **20** is a flow diagram illustrating an example process for assembling an implantable medical device, in accordance with one or more aspects of this disclosure.

FIG. **21** is a flow diagram illustrating an example process for assembling an implantable medical device with a permanent attachment on at least one electric contact assembly, in accordance with one or more aspects of this disclosure.

DETAILED DESCRIPTION

In general, this disclosure describes example techniques related to the arrangement of an electronic module and one or more electrical contact assemblies in an implantable medical device. An electrical contact assembly includes spring contacts to hold the electronics module in place within the housing of the implantable medical device. The electronic module and the electrical contact assemblies may be positioned between a side wall and an end cap of the housing. The battery, which provides power to the electronics module, can be positioned on the other side of the side wall from the electronics module.

The arrangement described herein can allow for simpler and fastest manufacturing process for implantable medical devices. For example, the one or more electrical contact assemblies may eliminate the need for soldering or other more labor intensive techniques for establishing electrical connections during assembly. The arrangement may also save space, allowing for smaller implantable medical devices using the techniques of this disclosure.

FIG. **1** is a conceptual diagram illustrating an example pacing device **12** implanted within a patient **14**. Pacing device **12** is an example of an implantable medical device that may include an arrangement of an electronics module and one or more electrical contact assemblies as described herein. Pacing device **12** may be, for example, an implantable leadless pacing device that is configured for implantation entirely within one of the chambers of heart **16**, and that provides electrical signals to heart **16** beneath sternum **22** via electrodes carried on the housing of pacing device **12**.

Pacing device **12** is generally described as being attached within a chamber of heart **16** as an intracardiac pacing device. In other examples that are consistent with aspects of this disclosure, pacing device **12** may be attached to an external surface of heart **16**, such that pacing device **12** is disposed outside of heart **16** but can pace a desired chamber. In one example, pacing device **12** is attached to an external surface of heart **16**, and one or more components of pacing device **12** may be in contact with the epicardium of heart **16**. Pacing device **12** is schematically shown in FIG. **1** attached to a wall of a ventricle of heart **16** via one or more fixation elements (e.g. tines, helix, etc.) that penetrate the tissue. These fixation elements may secure pacing device **12** to the cardiac tissue and retain an electrode (e.g., a cathode or an anode) in contact with the cardiac tissue. Pacing device **12** may be implanted at or proximate to the apex of the heart. In other examples, a pacing device may be implanted at other ventricular locations, e.g., on the free-wall or septum, an atrial location, or any location on or within heart **16**.

FIG. **2** is a conceptual illustration of an example configuration of pacing device **12**. Pacing device **12** is configured to be implanted within a chamber of a heart of a patient, e.g., to monitor electrical activity of the heart and/or provide electrical therapy to the heart. In the example shown in FIG. **2**, pacing device **12** includes outer housing **150**, a plurality of fixation tines **110** and electrodes **100** and **160**.

Outer housing **150** has a size and form factor that allows pacing device **12** to be entirely implanted within a chamber of a heart of a patient. In some examples, outer housing **150** may have a cylindrical (e.g., pill-shaped) form factor. Pacing device **12** may include a fixation mechanism configured to fix pacing device **12** to cardiac tissue. For example, in the example shown in FIG. **2**, pacing device **12** includes fixation tines **110** extending from housing **150** and configured to engage with cardiac tissue to substantially fix a position of housing **150** within the chamber of the heart **16**. Fixation tines **110** are configured to anchor housing **150** to the cardiac tissue such that pacing device **12** moves along with the cardiac tissue during cardiac contractions. Fixation tines **110** may be fabricated from any suitable material, such as a shape memory material (e.g., Nitinol). Although pacing device **12** includes a plurality of fixation tines **110** that are configured to anchor pacing device **12** to cardiac tissue in a chamber of a heart, in other examples, pacing device **12** may be fixed to cardiac tissue using other types of fixation mechanisms, such as, but not limited to, barbs, coils, and the like.

Housing **150**, also referred to as an elongated housing, houses electronic components of pacing device **12**, e.g., sensing circuitry for sensing cardiac electrical activity via electrodes **100** and **160** and therapy generation circuitry for delivering electrical stimulation therapy via electrodes **100** and **160**. Electronic components may include any discrete and/or integrated electronic circuit components that implement analog and/or digital circuits capable of producing the functions attributed to pacing device **12** described herein. In some examples, housing **150** may also house components for sensing other physiological parameters, such as acceleration, pressure, sound, and/or impedance. Although shown with both electrodes **100** and **160**, in some examples, housing **150** may only include one or the other of electrodes **100** and **160**.

Additionally, housing **150** may also house a memory that includes instructions that, when executed by processing circuitry housed within housing **150**, cause pacing device **12** to perform various functions attributed to pacing device **12** herein. In some examples, housing **150** may house communication circuitry that enables pacing device **12** to communicate with other electronic devices, such as a medical device programmer. In some examples, housing **150** may house an antenna for wireless communication. Housing **150** may also house a power source, such as a battery. Housing **150** can be hermetically or near-hermetically sealed in order to help prevent fluid ingress into housing **150**.

Pacing device **12** is configured to sense electrical activity of the heart and deliver electrical stimulation to the heart via electrodes **100** and **160**. Electrode **100** and/or electrode **160** may be mechanically connected to housing **150**. As another example, electrode **100** and/or electrode **160** may be defined by an outer portion of housing **150** that is electrically conductive. For example, electrode **160** may be defined by a conductive portion of housing **150**.

In the example of FIG. **2**, housing **150** includes a first portion **152**A and a second portion **152**B. Portion **152**B may, in some examples, define at least part of a power source case that houses a power source (e.g., a battery) of pacing device **12**. The power source case may house a power source (e.g., a battery) of pacing device **12**. In some examples, the portion **152**B may include the conductive portion of housing that forms electrode **160**.

Electrodes **100** and **160** are electrically isolated from each other. Electrode **100** may be referred to as a tip electrode, and fixation tines **110** may be configured to anchor pacing device **12** to cardiac tissue such that electrode **100** maintains contact with the cardiac tissue. In some examples, a portion of housing **150** may be covered by, or formed from, an insulative material to isolate electrodes **100** and **160** from each other and/or to provide a desired size and shape for one or both of electrodes **100** and **160**. Electrode **160** may be a portion of housing **150**, e.g., housing portion **152**B, that does not include such insulative material. Electrode **160** can be most or all of housing **150**, but most of housing **150** (other than electrode **160**, may be covered with an insulative coating. Additionally or alternatively, electrode **160** may be coated with materials to promote conduction. In some examples, electrode **160** may be part of a separate ring portion of housing **150** that is conductive. Electrodes **100** and **160**, which may include conductive portion(s) of housing **16**, may be electrically connected to at least some electronics of pacing device **12** (e.g., sensing circuitry, electrical stimulation circuitry, or both). In some examples, housing **150** may include an end cap **172**, which may include a feedthrough assembly to electrically couple electrode **100** to the electronics within housing **150**, while electrically isolating electrode **100** from housing **150**, e.g., including electrode **160** or other conductive portions of housing **150**.

In the example of FIG. **2**, the proximal end of pacing device **12** includes a flange **158** that defines an opening. Flange **158** may enable medical instruments to attach to pacing device **12**, e.g., for delivery and/or extraction of pacing device **12**. For example, a tether that extends through a catheter inserted into heart **16** (FIG. **1**) may be attached to flange **158** and/or threaded through the opening to implant or extract pacing device **12**.

FIG. **3** is a block diagram of an example configuration of implantable medical device **12** including a battery **180**, an electronics module **184**, and an electrical contact assemblies **186**A and **186**B. Although the implantable medical device of FIG. **3** is described as pacing device **12**, the structures shown in FIG. **3** can also be used in other implantable or external medical devices, such as cardioverter-defibrillators, physiological monitors, or neurostimulators, or any other electronic devices.

Housing **150** includes portions **152**A and **152**B and side wall **170** positioned within housing **150** between battery **180** and end cap **172**. Side wall **170** can be positioned within housing portions **152**B or **152**A or at the boundary of housing portions **152**A and **152**B. In some examples, housing portions **152**A and **152**B are common with a pole of battery **180**, such as the ground terminal (e.g., anode) of battery **180**. In some examples, one or both of housing portions **152**A and **152**B is non-conductive. For example, housing portion **152**A may be formed of a non-conductive material, such as sapphire, which may allow easier passage of electromagnetic signals from outside of housing **150** to antennae or the like within housing **150** then a metal or other conductive material.

As shown in the example of FIG. **3**, side wall **170** extends across housing **150** between battery **180** on one side and electrical contact assemblies **186**A and **186**B and electronics module **184** on the other side. Side wall **170** may include at least one feedthrough to allow for electrical connection **182** between battery **180** and electronics module **184**. As discussed above, end cap **172** may also include at least one feedthrough to allow for electrical connection **188** between electrode **100** and electronics module **184**. Electronics module **184** is positioned between and pressed against electrical contact assemblies **186**A and **186**B. Electrical contact assembly **186**B may be fixed to end cap **172** to provide mechanical support for electronics module **184**. Additionally or alternatively, electric contact assembly **186**A may be fixed to side wall **170** to provide mechanical support for electronics module **184**.

Pacing device **12** may also include battery header **181** positioned between battery **180** and electric contact assembly **186**A. Side wall **170** can form part of battery header **181**, or side wall **170** can be positioned between battery header **181** and end cap **172**, such as between battery header **181** and electric contact assembly **186**A. Battery header **181**, side wall **170**, and electric contact assembly **186**A may include means for electrically connecting battery to electronics module **184**. For example, battery header **181**, side wall **170**, and/or electric contact assembly **186**A may include feedthroughs and/or openings for creating an electrical connection between battery **180** and electronics module **184**.

Electrical contact assemblies **186**A and **186**B may be positioned on either side of electronics module **184**. Each of electrical contact assemblies **186**A and **186**B includes a spring contact for holding electronics module **184** in place and for providing electrical connections. Electronics module **184** can include a printed wiring board or a hybrid board with electronic components (integrated circuits, packages, capacitors, resistors, etc.) mounted on the board. In some examples, pacing device **12** includes only one of electrical contact assemblies **186**A and **186**B on one side of electronics module **184**.

The design of pacing device **12** shown in FIG. **3** resolves many of the manufacturing issues with other implantable medical devices. For example, the manufacturing process for another implantable medical device may include laser soldering of battery and electrode feedthrough pins to create connections from the electronics module to the battery and electrode. The laser soldering may be difficult and expensive as compared to using electrical contact assemblies **186**A and **186**B to provide the electrical contacts between electronics module **184** and the battery and electrodes, which is possible in the design of pacing device **12**. Electrical contact assemblies can reduce the cost and complexity of interconnect components, especially as compared to laser soldering.

Pacing device **12** can be manufactured with a single tube for housing portion **152**A or as two tube sections for portion **152**A. Using a single tube for housing portion **152**A, in contrast to two sections, e.g., two half-pipes, lowers the cost and complexity of the encasement for pacing device **12**. A single tube opens up new encasement options and can be manufactured from alternate materials. For example, a single sapphire tube for housing portion **152**A can allow for wireless charging of battery **180** even when pacing device **12** is implanted within a patient. Additionally, using a single tube for housing **150** or using two single-tube portions **152**A and **152**B, as well as the layout of the components within housing **150** shown in FIG. **3**, can reduce the overall size of pacing device **12**, which is especially important for a device designed for implantation in the heart or pulmonary artery. A single tube reduces the manufacturing time for pacing device **12** because using two half-pipe sections means additional steps in the manufacturing process.

Use of a single tube may by enabled due the component interconnection methods described herein, which may remove the need for access to the components to complete the assembly and interconnect processes. Many interconnection methods, such as solder, conductive epoxy, and welding, require access to the joints between the components of pacing device **12**. A split-case, half-pipe design allows closure of the encasement after the interconnection operation. On the other hand, spring contacts may allow a single tubular housing because the contact can be blind mated without access for a joining process between the spring contacts and the electronics module. The electric contact assemblies described herein can remove the need for gaining access to the assembly to complete the interconnection process. Thus, pacing device **12** may include a single tube because the manufacturing process may not include welding the electronics module to an electric contact assembly.

As shown in FIGS. **4-10** and **18**A, electrical contact assemblies **186**A and **186**B can include spring contacts with spring fingers to make contact with electronics module **184**. Electronics module **184** can be suspended between and/or held in place by the fingers of electrical contact assembly **186**A and electrical contact assembly **186**B. In examples in which electronics module **184** includes a circuit board or a wiring board, the spring fingers of electrical contact assemblies **186**A and **186**B can contact and electrically connect to the electrically conductive areas (e.g., the plated edges) of the board. The spring fingers can apply pressure to the pads on the board, e.g., the board edge, to hold electronics module **184** in place.

FIGS. **4-10** show example designs for each of electrical contact assemblies **186**A and **186**B that includes four fingers. Four fingers provide redundant springs for mechanical and structural integrity for pacing device **12**. In the four-finger implementation, each of electrical contact assemblies **186**A and **186**B can include two fingers of each polarity (e.g., the anode and cathode of battery **180**). One or more of the poles of battery **180** are connected to the spring arms of electric contact assemblies **186**A and/or **186**B. In addition, FIG. **18**A shows an example two-finger design for each of electrical contact assemblies **186**A and **186**B. The two fingers provide redundant springs for mechanical and structural integrity for pacing device **12**.

The manufacturing and assembly process for pacing device **12** can include first forming housing portion **152**B and side wall **170**. The manufacturing process then includes the installation of battery **180** in housing portion **152**B behind side wall **170** and sealing of side wall **170** to housing portion **152** to enclose battery **180** therein. Electrical contact assembly **186**A is connected to side wall **170**, and electrical connection **182** is formed between battery and electrical contact assembly **186**A. Electrical connections **182** and **188** may be hermetic feedthrough conductive paths that pass the otherwise hermetic housing of pacing device **12**. In examples in which housing **150** includes two single-tube pieces (e.g., portions **152**A and **152**B in a split-case design), portion **152**A can be installed over electrical contact assembly **186**A and attached to side wall **170** and portion **152**B.

Electronics module **184** is then inserted into the open end of portion **152**A put into contact with electrical contact assembly **186**A. End cap **172** is mounted on portion **152**A, where end cap **172** may have electrical contact assembly **186**B already attached. Electrical contact assembly **186**B comes into contact with electronics module **184** as end cap **172** is mounted on portion **152**A. Mounting end cap **172** pushes electrical contact assembly **186**B against electronics module **184**, which pushes electronics module **184** against electrical contact assembly **186**A. End cap **172** may include a feedthrough extending through end cap **172** to create an electrical connection with an electrode (e.g., electrode **100**) on end cap **172**. Thus, the board of electronics module **184** is loaded onto the pins of electrical contact assemblies **186**A and **186**B, providing electrical connection between the electrical contacts and the electronic circuitry of electronics module **184**.

In some examples, there may be three electrical paths that leave the hermetic chamber. On the end with battery **180**, pacing device **12** may include a battery pin (e.g., electrical connection **182**) and case ground, where the battery pin can be connected to a first pole (e.g., cathode) of battery **180**, and the case ground can be connected to a second pole (e.g., anode) of battery **180**. Case ground on the end with battery **180** can be connected to housing portion **152**B. On the end with end cap **172**, pacing device **12** may include an electrode pin (e.g., electrical connection **188** and electrode **100**) and case ground. Case ground on the end with end cap **172** can be connected to housing portion **152**A. The case ground on each end may be electrical connected across pacing device **12** (e.g., only one case ground for the entire device), or there may be two separate case ground elements where there is an insulating material between the elements. For example, a sapphire or ceramic tube around electronics module **184** can result in two case ground potentials. Even in examples in which there is a single case ground, the case ground may be redundantly connected to electric contact assemblies **184**A and **184**B. In some examples, there may be more than one pin on each end, resulting in more than three electrical paths passing through the hermetic seal.

Electric contact assembly **186**A may have a single-channel configuration or a multiple-channel configuration. In a single-channel configuration, electric contact assembly **186**A provides a single electrical channel between battery **180** and electronics module **184**. In the single-channel configuration, the spring contact(s) of electric contact assembly **186**A can be electrically connected to a first pole of battery **180**, and housing portions **152**A and **152**B can be electrically connected to a second pole of battery **180**.

In a double-channel configuration, electric contact assembly **186**A provides two electrical channels between battery **180** and electronics module **184**. In the double-channel configuration, a first set of one or more spring contacts of electric contact assembly **186**A can be electrically connected to a first pole of battery **180**, and a second set of one or more spring contacts of electric contact assembly **186**A can be electrically connected to a second pole of battery **180**. In the double-channel configuration, housing portions **152**A and **152**B can also be electrically connected to one of the poles of battery **180**. A single-channel configuration allows for a simpler construction and simpler assembly, as compared to a multiple-channel configuration, because of fewer electrical connections that are formed through electric contact assembly **186**A.

FIGS. **4-6** are diagrams of example electric contact assembly **486**, in accordance with one or more aspects of this disclosure. Electric contact assembly **486** includes conductive portions **410** and **420**, spring contacts **430**, **432**, **434**, and **436**, and insulative portion **440**. Electric contact assembly **486** is just one example configuration of electric contact assemblies **186**A and **186**B shown in FIG. **3**. In some examples, electric contact assembly **486** may include more than or fewer than four spring contacts. For example, electric contact assembly **486** may include only one spring contact. In addition, although FIG. **3** depicts pacing device **12** as including two electric contact assemblies, an implantable medical device may include any number of electric contact assemblies, including only one electric contact assembly.

In the example shown in FIGS. **4-6**, conductive portion **410** is electrically connected to spring contacts **430** and **436**, and conductive portion **420** is electrically connected to spring contacts **432** and **434**. Thus, electric contact assembly **486** may be used in a double-channel configuration, where each of conductive portions **410** and **420** is electrically connected to a respective pole of a battery, and conductive portion **410** is electrically isolated from conductive portion **420**. For example, conductive portion **410**, along with spring contacts **430** and **436**, may be electrically connected to a first pole (e.g., an anode) of the battery. Conductive portion **420**, along with spring contacts **432** and **434**, may be electrically connected to a second pole (e.g., a cathode) of the battery. In a single-channel configuration, conductive portion **410** may be electrically connected to conductive portion **420**, such that all of spring contacts **430**, **432**, **434**, and **436** are all connected to the same pole of a battery.

After assembly of an implantable medical device, an electronics module (not shown in FIGS. **4-6**) may be in contact with spring contacts **430**, **432**, **434**, and **436**. For example, the plated edges of a circuit board of an electronics module may be in contact with spring contacts **430**, **432**, **434**, and **436**, forming one or more electrical connections between spring contacts **430**, **432**, **434**, and **436** and the components on the circuit board. Additionally or alternatively, the metalized ends of an electronics module may be in contact with spring contacts **430**, **432**, **434**, and **436**. Thus, each of spring contacts **430**, **432**, **434**, and **436** can act as a power rail or power supply for the electronics module, such as a high-side power rail (e.g., Vcc or Vdd) and/or a low-side power rail (e.g., reference ground).

In a multiple-channel configuration, outside spring contacts **430** and **436** may be electrically connected to a case ground, and inside spring contacts **432** and **434** may be electrically connected to a feedthrough pin. The center hole of conductive portion **410** can be welded or soldered to a conductor that is connected to case ground, or to case ground itself, and the center hole of conductive portion **420** can be welded or soldered to a feedthrough pin. In some examples, electric contact assembly **486** may include more than two electrical paths such that there may be a connection to case ground, and two or more connections to two or more pins. Thus, electric contact assembly **486** may include additional spring contacts for connecting to another pin.

Electric contact assembly **486** may also include one or more holes or openings in conductive portions **410** and **420** and insulative portion **440**. These openings may receive feedthroughs pins for making electrical connections to a battery through a housing of the battery, which may be positioned in the negative x-axis relative to electric contact assembly **486**. A conductive element, such as wire, pin, or a metal plate, can be fed through the holes in conductive portions **410** and **420** and insulative portion **440** or form the electrical connections between each of conductive portions **410** and **420** and the battery. In some examples, the feedthrough includes a conductive pin extending through an electrically insulating material, such as glass, of the side wall.

Conductive portions **410** and **420** and insulative portion **440** may be arranged coplanar in the y-axis and z-axis directions. Electric contact assembly **486** is shown with a circular shape for installation inside a cylindrical-shaped implantable medical device, where the x-axis is the longitudinal axis of the implantable medical device. Spring contacts **430**, **432**, **434**, and **436** extending in the x-axis direction out of the plane of conductive portions **410** and **420** and out of the plane of insulative portion **440**. FIGS. **5** and **6** show a side view of electric contact assembly **486** with spring contact **436** in two positions. In FIG. **5**, spring contact **436** is extending in the x-axis direction to a greater extent than shown in FIG. **6**, where spring contact **436** is shown closer to the plane of conductive portions **410** and **420** and insulative portion **440**. As shown in FIGS. **4-6**, spring contacts **430**, **432**, **434**, and **436** may be pushed back towards insulative portion **440** when in contact with an electronics module.

Insulative portion **440** is an insulative backing for conductive portions **410** and **420**. Conductive portions **410** and **420** are mounted to insulative portion **440** in the example shown in FIGS. **4-6**. Spring contacts **430**, **432**, **434**, and **436** are shown in FIGS. **4-6** as biased away from insulative portion **440**. However, when an electronics module is pressed against spring contacts **430**, **432**, **434**, and **436**, spring contacts **430**, **432**, **434**, and **436** may be configured to flex or bend back towards insulative portion **440**.

Spring contacts **430**, **432**, **434**, and **436** may also be referred to as "spring arms," "contact arms," or "spring fingers" because spring contacts **430**, **432**, **434**, and **436** can hold an electronics module in place. Spring contacts **430**, **432**, **434**, and **436** are shown in FIGS. **4-6** as straight (e.g., without bends), except for the joint between each of spring contacts **430**, **432**, **434**, and **436** and the respective one of conductive portions **410** and **420**. For example, spring contact **430** has a straight, rectangular shape with a flexed joint where spring contact meets conductive portion **410**. In some examples, an electric contact assembly includes two spring contacts, where each spring contact is electrically connected to a pole of the battery. As compared to an electric contact assembly with only one or two spring contacts, four spring contacts **430**, **432**, **434**, and **436** of electric contact assembly **486** provide redundancy and additional structural integrity to reduce the likelihood of single-point failures. However, an electric contact assembly with one or two spring contacts may still provide structural integrity while reducing the number of mechanical and/or electrical connections that are formed between the electric contact assembly and an electronics module.

FIG. **5** is an example of the position of spring contact **436** in an unstressed state, and FIG. **6** is an example of position of spring contact **436** in a stressed state, when an electronics module is being held by spring contacts **430**, **432**, **434**, and **436**. Spring contacts **430**, **432**, **434**, and **436** may be flexible, allowing spring contacts **430**, **432**, **434**, and **436** to be pressed into the position shown in FIG. **6**. When spring contact **436** is pressed into the position shown in FIG. **6** by an electronics module, the positive z-axis end of spring contact **436** may exert a force on the electronics module in the positive x-axis direction. This force can hold or suspend the electronics module in place without any welding or laser soldering of the electronics module to an electric contact assembly. The springiness and flexibility of spring contacts **430**, **432**, **434**, and **436** is based on the length and material used for spring contacts **430**, **432**, **434**, and **436**.

FIGS. **7** and **8** are diagrams of an example electric contact assembly **786** attached to an insulative backing **770**, in accordance with one or more aspects of this disclosure. Electric contact assembly **786** includes conductive portions **710** and **720**, spring contacts **730**, **732**, **734**, and **736**, and insulative portion **740**. In a multiple-channel configuration, each of conductive portions **710** and **720** is electrically connected to a respective pole of a battery, conductive portion **710** is electrically isolated from conductive portion **720**. In a single-channel configuration, conductive portion **710** may be electrically connected to conductive portion **720**.

Electric contact assembly **786** is just one example configuration of electric contact assemblies **186**A and **186**B shown in FIG. **3**. In some examples, electric contact assembly **786** may include more than or fewer than four spring contacts. In addition, although FIG. **3** depicts pacing device **12** as including two electric contact assemblies, an implantable medical device may include any number of electric contact assemblies, including only one electric contact assembly.

Electric contact assembly **786** may be formed by welding portions **710**, **720**, **740**, and/or **770** using contact welding. Electric contact assembly **786** includes openings **782**A and **782**B for creating an electrical connection between conductive portions **710** and **720** and a battery. The electrical connection can be formed by a feedthrough that extends through insulative backing **770**, a side wall, and/or a battery header. The battery header may be connected to insulative backing **770** opposite spring contacts **730**, **732**, **734**, and **736**.

Conductive portions **710** and **720** may include titanium with an example thickness of approximately 0.002 to 0.005 inches. Insulative portion **740** can be polyimide bonded to conductive portions **710** and **720**. Spring contacts **730**, **732**, **734**, and **736** may include an electrically conductive plating with a material such as gold, silver, titanium, or another metal. Insulative backing **770** can include a loose insulator material.

FIGS. **9**A-**9**B are diagrams of an example spring contact **930** of an electric contact assembly, in accordance with one or more aspects of this disclosure. In the example shown in FIG. **9**A, spring contact **930** includes two ribs **931**A and **931**B (e.g., raised contact surfaces) that protrude from spring contact **930** for making contact with an electronics module. Ribs **931**A and **931**B shown in FIG. **9**A are raised islands on spring contact finger **930** for contact interface with the plated edge of a circuit board. Ribs **931**A and **931**B may be plated with a metal such as gold, silver, aluminum, or another metal. Spring contact **930** may also have gold coverage on portions of spring contact **930** other than ribs **931**A and **931**B. Spring contact **930** may be titanium material or another suitable material that is 0.005 inches thick. Ribs **931**A and **931**B can increase the number of contact points between the electric contact assembly and a circuit board or wiring board.

The portion of spring contact **930** that does not have ribs **931**A and **931**B may be depth etched so that the titanium is only 0.002 to 0.003 inches to reduce the beam stiffness and created the raised profile of ribs **931**A and **931**B. The depth etching can result in a thicker metal at the pin weld for process margin and a thinner area in the beam to control forces. In some examples, ribs **931**A and **931**B can be formed using a process other than depth etching.

Ribs **931**A and **931**B may also hold the electronics module suspended in place. Spring contacts **430**, **432**, **434**, and **436** illustrated in FIGS. **4**-**6**, spring contacts **730**, **732**, **734**, and **736** of FIGS. **7** and **8**, or any spring contacts described herein may also include ribs with a structure similar to ribs **931**A and **931**B shown in FIG. **9**A. In some examples, each spring contact can include one, two, three, or any other number of ribs for making contact with an electronics module.

Spring contact **930** shown in FIG. **9**B has a different shape than spring contacts **430**, **432**, **434**, and **436** shown in FIGS. **4**-**6**. Spring contact **930** includes bend **960** where spring contact **930** meets conductive portion **910**. Spring contact **930** also includes a bend **962** between joint **960** and end **964** of spring contact **930**. Between bend **962** and end **964**, spring contact **930** may extend parallel with the z-axis direction (e.g., coplanar with conductive portion **910**, insulative portion **940**, and side wall **970**). Spring contact **930** is biased away from side wall **970**, the battery, and the battery header so that spring contact **930** can flex towards side wall **970** when a circuit board is pressed against spring contact **930**.

FIG. **9**B shows spring contact **930** in two possible positions: an unconstrained position and an installed position. Bend **992** and end **994** show the unconstrained position when spring contact **930** is not in contact with an electric contact assembly. Bend **962** and end **964** show the installed position when an electric contact assembly is pushed against spring contact **930**. The force applied by the electric contact assembly moves spring contact **930** in the negative x-axis direction.

FIGS. **10** and **11** are diagrams of an example implantable medical device (e.g., implantable medical device **12**) including the circuit board **1090** of an electronics module (e.g., electronics module **184**), in accordance with one or more aspects of this disclosure. In the example shown in FIGS. **10** and **11**, circuit board **1090** is suspended between electric contact assemblies **1086**A and **1086**B. Implantable medical device **100** is an example of a "dual spring on a circuit board" device, where the spring contacts of electric contact assemblies **1086**A and **1086**B may be pressed against circuit board **1090**. Electric contact assembly **1086**B is positioned proximate end cap **1072**, and electric contact assembly **1086**A is positioned proximate housing portion **1052**B. A battery may be positioned within housing portion **1052**B.

One or more of the spring contacts of electric contact assemblies **1086**A and **1086**B are in contact with the conductive portions of circuit board **1090**. The spring contacts of electric contact assembly **1086**A flex or bend towards the side wall and/or battery header when circuit board **1090** is held between electric contact assemblies **1086**A and **1086**B. The spring contacts of electric contact assemblies **1086**A and **1086**B may apply pressure on circuit board **1090** in the x-axis direction. For example, the plated spring contacts may be in contact with the plated edges of circuit board **1090**. Spring contacts may form electrical connections between a battery (not shown in FIGS. **10** and **11**) and the traces, vias, and mounted components of circuit board **1090**. Circuit board **1090** may include a printed circuit board (PCB), a printed wiring board (PWB), a hybrid PCB/PWB, and/or any other type of board.

The spring contact(s) of electric contact assemblies **1086**A and **1086**B may be soldered or otherwise permanently attached to electronics module **1084**. In some examples, the spring contact(s) of only one of electric contact assemblies **1086**A and **1086**B is permanently attached (e.g., soldered or glued) to electronics module **1084**, while the spring contact(s) of the other of electric contact assemblies **1086**A and **1086**B is attached to electronics module **1084** in a non-permanent manner (e.g., pressed against).

Although each of electric contact assemblies **1086**A and **1086**B are depicted in FIGS. **10** and **11** with four spring contacts, electric contact assembly **1086**A or **1086**B may have only one spring contact. Additionally or alternatively, electric contact assembly **1086**A or **1086**B may have an electrical contact that does not include a spring. In examples in which electric contact assembly **1086**A or **1086**B has only one spring contact, the other electric contact assembly (e.g., the feedthrough end of electronics module **1084**) may be soldered or otherwise permanently attached to electronics module **1084**. The non-permanently attached side of electronics module **1084** may be pressed against the electric contact assembly, which may only have one spring contact. The one spring contact may be connected to, for example, the reference ground for implantable medical device **1000**.

In some examples, an electronics module may include an electrically insulative housing mounted to circuit board **1090**. The insulative housing may include end walls that come into contact with electric contact assemblies **1086**A and **1086**B. The end walls of the insulative housing may contain conductive pads and traces that contact and connect to the spring fingers of electric contact assemblies **1086**A and **1086**B. A first end wall may face the battery header and a second end wall may face end cap **1072**. Each end wall may include a metalized area for contacting a spring contact and forming an electrical connection with the spring contact.

FIG. **12** is a diagram of an example implantable medical device **1200** including an electronics module **1284** with electronics components mounted on a circuit board **1290**, in accordance with one or more aspects of this disclosure. The components that are mounted on or attached to circuit board **1290** can include integrated circuits, capacitors, resistors, and/or any other electrical components. Electronics module **1284** may also include an antenna, either as an integrated circuit mounted on circuit board **1290** or as a patch antenna that is built into circuit board **1290**. Implantable medical device **1200** includes a longitudinal axis along the x-axis. The major surface of circuit board **1290** faces the positive and negative z-axis directions, which are perpendicular to the x-axis direction.

Implantable medical device **1200** is shown in FIG. **12** as including housing portion **1252**B but without a second housing portion to reveal electronics module **1284**. FIGS. **13** and **14** show two example configurations for the second housing portion. The second housing portion can have a cylindrical shape and extend from housing portion **1252**B to end cap **1272**. Electrode **1274** can be welded to the feedthrough conductive path that passes through the hermetic enclosure of implantable medical device **1200** to connect to a spring contact of an electric contact assembly.

FIGS. **13** and **14** are exploded view diagrams of two example implantable medical devices **1300** and **1400**, in accordance with one or more aspects of this disclosure. Implantable medical device **1300** includes two half cylindrical housing portions **1354**A and **1354**B enclosing electronics module **1384**. Implantable medical device **1300** also includes electric contact assemblies **1386**A and **1386**B to hold electronics module **1384** in place. The spring contacts of electric contact assemblies **1386**A and **1386**B can press against contact areas on electronics module **1384**. Electronics module **1384** may include two contact areas on each side, where each contact area is configured to electrically connect to a pole of the battery on a first end of electronics module **1384**. For example, electronics module **1384** may be electrically connected to the electrode feedthrough on the other end. The contact area on each side of electronics module **1384** may be a joint pad soldered to the circuit board of electronics module **1384**. Electric contact assembly **1386**A may be attached to side wall **1370**, which can include a feedthrough for electrically connecting electronics module **1384** to a battery. Electric contact assembly **1386**B may be attached to end cap **1372**, which can include a feedthrough for electrically connecting electronics module **1384** to an electrode, such as electrode **100** (see FIGS. **2** and **3**).

After electronics module **1384** is positioned on electric contact assembly **1386**A, housing portions **1354**A and **1354**B can be installed to enclose electronics module **1384**. During the manufacturing process, housing portions **1354**A and **1354**B can be put together to form a sleeve. Housing portion **1354**A may be attached to housing portion **1354**B by welding, laser soldering, or another attachment method. In some examples, a first one of housing portions **1354**A and **1354**B may be attached to side wall **1370** and/or end cap **1372** prior to positioning electronic module **1384**, and then the second one of housing portions **1354**A and **1354**B (e.g., the "lid") may be attached to the side wall and the first housing portion to surround the electronic module. Electric contact assembly **1386**B and end cap **1372** may be pressed against electronics module **1384** so that the spring contacts of electric contact assemblies **1386**A and **1386**B hold electronics module **1384** in place.

As shown in FIG. **13**, electronics module **1384** includes a metalized housing that extends off circuit board **1390** of electronics module **1384** in the y-axis direction. Electronics module **1384** includes plastic housing with metalized doors, strips, or panels on the end of the plastic housing. Each spring contact of electric contact assemblies **1386**A and **1386**B may come in contact with a metalized door of electronics module **1384** to form an electrical connection. The metalized panels of electronics module **1384** can be soldered to circuit boar **1390**.

Implantable medical device **1300** can be assembled by connecting housing portions **1354**A and **1354**B and welding housing portions **1354**A and **1354**B to end cap **1372**. Electric contact assembly **1386**B may have been already attached to end cap **1372** before housing portions **1354**A and **1354**B are welded to end cap **1372**. Then electronics module **1384** can be slid into the space that is partially enclosed by housing portions **1354**A and **1354**B and end cap **1372**. Side wall **1370**, which is attached to the header of the battery, is added to the assembly to close the canister and trap electronics module **1384** between the spring contacts of electric contact assemblies **1386**A and **1386**B. Side wall **1370** can be welded to housing portions **1354**A and **1354**B.

FIG. **14** depicts implantable medical device **1400** includes two cylindrical housing portions **1452**A and **1452**B enclosing electronics module **1484**. Implantable medical device **1400** also includes electric contact assemblies **1486**A and **1486**B to hold electronics module **1484** in place. Electric contact assembly **1486**A may be attached to side wall **1470**, which can include a feedthrough for electrically connecting electronics module **1484** to a battery. Side wall **1470** is attached to housing portion **1452**B in the example shown in FIG. **14**. Electric contact assembly **1486**B may be attached to end cap **1472**, which can include a feedthrough for electrically connecting electronics module **1484** to an electrode, such as metal fixation tines.

After housing portion **1452**A can be installed, electronics module **1484** can be inserted into housing portion **1452**A and positioned on electric contact assembly **1486**A. Housing portion **1452**A may include sapphire material that is covered by another material and/or is covered by another case. Additionally or alternatively, housing portion **1452**A may include a titanium tube. Electric contact assembly **1486**B and end cap **1472** may be pressed against electronics module **1484** so that the spring contacts of electric contact assemblies **1486**A and **1486**B hold electronics module **1484** in place. Housing portion **1452**A may be attached to housing portion **1452**B and end cap **1472** by welding, laser soldering, or another attachment method.

By using electric contact assemblies **1486**A and **1486**B, the assembly process may not include welding, soldering, or otherwise processing electronics module **1484** to electric contact assemblies **1486**A and **1486**B. The electrical connection between electronics module **1484** and electric contact assemblies **1486**A and **1486**B can be created using the assembly pressure of electronics module **1484** on the electric contact assemblies **1486**A and **1486**B. A single tube can be used for housing portion **1452**A because electronics module **1484** can be inserted into housing portion **1452**A and electrical connections can be formed between electronics module **1484** and the battery without welding. Therefore, electric contact assemblies **1486**A and **1486**B eliminate the need for welding, laser soldering, or other more labor-intensive techniques for establishing electrical connections during assembly. Moreover, electric contact assembly **1486**A and **1486**B take up less space, use simpler components, and eliminates the need for access to the components to complete the assembly and interconnect processes, as compared to other connection techniques. Thus, electric contact assemblies **1486**A and **1486**B may result in lower complexity and lower manufacturing costs, as compared to using two half-pipe sections for housing portion **1452**A.

The single tube for housing portion **1452**A may include materials such as sapphire, ceramics, other non-metallic materials, other electrically insulative materials, metallic materials, electrically conductive materials, and/or other materials. For example, housing portion **1452**A may include titanium ends and a sapphire midsection. The use of titanium or other metals allows for welding. The titanium can be diffusion bonded to the sapphire at high temperatures, or the titanium may be gold-brazed.

FIGS. **15-17** are exploded view diagrams of an example implantable medical device **1500**, in accordance with one or more aspects of this disclosure. As shown in FIGS. **15-17**, the circuit layers of electronics module **1584** are oriented perpendicular to the longitudinal axis of implantable medical device **1500** (e.g., the x-axis direction), where the longitudinal axis extends between the ends of implantable medical device **1500**. Whereas circuit board **1290** shown in FIG. **12** is parallel with the x-y plane, the circuit layers of electronics module **1584** are parallel with the y-z plane. Thus, electronics module **1584** shown in FIGS. **15-17** has a different orientation than electronics module **1284** shown in FIG. **12**. In the example shown in FIGS. **15-17**, electronics module **1584** includes three circuit layers, where each layer may include a circuit board and/or another structure include electronics components. Each layer may include a silicon chip overmolded in epoxy, where the chip is embedded in the epoxy. Thus, each circuit layer of electronics module **1584** defines a plane that intersects the longitudinal axis at a single point because the plane of each circuit layer is normal to the longitudinal axis. FIGS. **15-17** depicts each circuit layer of electronics module **1584** as arranged parallel to the other circuit layers.

Electric contact assembly **1586**B can be attached to end cap **1572** before installing electronics module **1584**. A second side of electronics module **1584** is attached to electric contact assembly **1586**B and end cap **1572** by soldering or other attachment means (e.g., conductive epoxy). Electronics module **1584** is then installed by pressing a first side of electronics module **1584** against electric contact assembly **1586**A. A housing portion (not shown in FIGS. **15-17**) can be installed over electronics module **1584**, and end cap **1572**. The spring contacts of electric contact assembly **1586**A and housing portion **1552**B are welded to the header of end cap **1572** and the flange of the battery inside housing portion **1552**B.

As shown in FIG. **17**, electric contact assembly **1586**B may not include any spring contact fingers. Instead, electric contact assembly **1586**B can include solder bumps arranged on two conductive portions of electric contact assembly **1586**B. The solder bumps of electric contact assembly **1586**B may be pre-formed solder bumps that are reflowed to permanently connect a layer of electronics module **1584**. The orientation of the layers of electronics module **1584** can make the connection process electric contact assembly **1586**B easier than for a perpendicular circuit board as shown in FIGS. **10-14**. Electric contact assembly **1586**B may include redundant solder points for contacting electronics module **1584**. The solder points may be attached to a titanium plate using a sputter process by sputtering the titanium with nickel vanadium to make the titanium solderable. However, in some examples, both of electric contact assemblies **1586**A and **1586**B may include spring contacts, as shown for electric contact assembly **1586**A in FIG. **16**.

Each conductive portion of electric contact assembly **1586**B may be electrically connected to a pole of the battery. In a single-channel configuration, all of the conductive portions of electric contact assembly **1586**B may be connected to the same pole of a battery. In a multiple-channel configuration, a first conductive portion of electric contact assembly **1586**B may be connected to a first pole of a battery, and a second conductive portion of electric contact assembly **1586**B may be connected to a second pole of the battery. Electric contact assembly **1586**B may be spring finger flattened and soldered, thermal compression bonded, and/or epoxy bonded. Electronics module **1584** is rotated ninety degrees with respect to the electronics modules of FIGS. **10-14**, which makes soldering the board of electronics module **1584** to electric contact assembly **1586**B more practical. Electronics module **1584** and electric contact assembly **1586**B may be combined as a layered assembly for use as a build platform in the assembly process. The build platform may be inserted as a single piece into housing portion **1552**B. Thus, there may be not be a housing portion between end cap **1572** and housing portion **1552**B.

FIG. **18**A is a diagram of an example implantable medical device **1800** including an electric contact assembly **1886**A with two spring fingers **1830** and **1832**, in accordance with one or more aspects of this disclosure. Implantable medical device **1800** includes a single-channel battery connection for electric contact assembly **1886**A, where spring finger **1830** is electrically connected to spring finger **1832**. Spring fingers **1830** and **1832** may be electrically connected to a first pole of the battery, housing portion **1852**A may be electrically connected to a second pole of the battery, and spring fingers **1830** and **1832** may be electrically isolated from housing portion **1852**A. FIG. **18**A does not show the internal battery connections or a second housing portion that may be connected to housing portion **1852**B. In addition, spring fingers **1830** and **1832** may be electrically connected to an electrode on the exterior of IMD **1800**.

In the example shown in FIG. **18**A, electric contact assembly **1886**A is mounted on side wall **1834**. Side wall **1834** can electrically insulate electric contact assembly **1886**A from housing portion **1852**A. Electric contact assembly **1886**A can electrically connect an electronics module to a first pole of the battery, and housing portion **1852**A may electrically connect the electronics module to a second pole of the battery through a second electric contact assembly and a second housing portion (not shown in FIG. **18**).

Housing portion **1852**A can be welded to a second housing portion that is not shown in FIG. **18**A to complete the connection of the second battery pole. Electric contact assembly **1886**A may allow for forming a weld at a different position on housing portion **1852**A, as compared a weld formed between housing portions **1452**A and **1452**B, as shown in FIG. **14**. For example, a weld may be formed on side wall **1836** between housing portion **1852**B and another housing portion that is not shown in FIG. **18**A.

In the example shown in FIG. **18**A, spring fingers **1830** and **1832** (e.g., spring beams and/or spring arms) are arranged in a mirrored configuration where spring finger **1830** extends from side wall **1834** in the positive z-axis direction, and spring finger **1832** extends from side wall **1834** in the negative z-axis direction. When an electronics module is pressed against electric contact assembly **1886**A, spring finger **1830** may provide a force in the negative x-axis direction and in the negative z-axis direction, and spring finger **1832** may provide a force in the negative x-axis direction and in the positive z-axis direction. The mirrored configuration of spring fingers **1830** and **1832** can provide structural stability when an electronics module is connected to spring fingers **1830** and **1832**. In some examples, spring fingers **1830** and **1832** may have a shape that is similar to spring contacts **430**, **432**, **434**, and **436** shown in FIGS. **4-6**, a shape that is similar to spring contacts **730**, **732**, **734**, and **736** shown in FIGS. **7** and **8**, and/or a shape that is similar to the spring contacts shown in FIGS. **9**A and **9**B.

As shown in FIG. **18**A, electric contact assembly **1886**A includes a weld tab in the feedthrough pin interface, whereas electric contact assembly **1886**A shown in FIG. **18**B includes a plate and a pin extending through the plate. Thus, the weld configuration for electric contact assembly **1886**A shown in FIG. **18**A is different from the weld configuration for electric contact assembly **1886**A shown in FIG. **18**B.

FIG. **18**B is a cut-away diagram of an example implantable medical device **1800** including an end cap **1872** and a feedthrough header **1874**, in accordance with one or more aspects of this disclosure. Feedthrough header **1874** provides an electrical channel for electrode **1878** to pass through the exterior of implantable medical device **1800**. When implantable medical device **1800** is implanted in the body of a patient, electrode **1878** may be in contact with the tissue of the patient.

During the construction of implantable medical device **1800**, a weld may be formed at the interface of end cap **1872** and feedthrough header **1874**. Another implantable medical device, such as implantable medical devices **1400** and **1300** shown in FIGS. **13** and **14**, may include a weld on the outside diameter of a housing portion. Location **1876** shown in FIG. **18**B is one example of a position for a weld on the outside diameter of a housing portion.

FIG. **19** is a conceptual block diagram of an example implantable medical device **1900**, in accordance with one or more aspects of this disclosure. In the illustrated example, implantable medical device **1900** includes processing circuitry **1990**, memory **1992**, therapy generation circuitry **1996**, sensing circuitry **1998**, motion sensor **1980**, and communication circuitry **1994**. One or more of the elements of implantable medical device **1900** may be part of an electronics module. For example, processing circuitry **1990**, memory **1992**, therapy generation circuitry **1996**, sensing circuitry **1998**, motion sensor **1980**, and/or communication circuitry **1994** may be mounted on a circuit board of an electronics module of implantable medical device **1900**.

Memory **1992** includes computer-readable instructions that, when executed by processing circuitry **1990**, cause implantable medical device **1900** and processing circuitry **1990** to perform various functions of implantable medical device **1900** such as storing and analyzing signals received by implantable medical device **1900** and providing pacing therapy for a patient's heart. Example details of functions of implantable medical device **1900** can be found in commonly assigned U.S. Patent Application Publication No. 2019/0209845 entitled "Adaptive Cardiac Resynchronization Therapy," filed on Mar. 22, 2018, the entire contents of which are incorporated herein by reference.

Memory **1992** may include any volatile, non-volatile, magnetic, optical, or electrical media, such as a random-access memory (RAM), read only memory (ROM), non-volatile RAM (NVRAM), electrically-erasable programmable ROM (EEPROM), flash memory, or any other digital or analog media.

Processing circuitry **1990** may include any one or more of a microprocessor, a controller, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field-programmable gate array (FPGA), or equivalent discrete or analog logic circuitry. In some examples, processing circuitry **1990** may include multiple components, such as any combination of one or more microprocessors, one or more controllers, one or more DSPs, one or more ASICs, or one or more FPGAs, as well as other discrete or integrated logic circuitry. The functions attributed to processing circuitry **1990** herein may be embodied as software, firmware, hardware or any combination thereof.

Processing circuitry **1990** controls therapy generation circuitry **1996** to deliver stimulation therapy to a patient's heart according to therapy parameters, which may be stored in memory **1992**. For example, processing circuitry **1990** may control therapy generation circuitry **1996** to deliver electrical pulses with the amplitudes, pulse widths, frequency, or electrode polarities specified by the therapy parameters. In this manner, therapy generation circuitry **1996** may deliver pacing pulses to the heart via electrodes **1952**, **1956**, and/or **1960**. Although implantable medical device **1900** may only include two electrodes, e.g., electrodes **1952** and **1960**, implantable medical device **1900** may utilize three or more electrodes in other examples. Implantable medical device **1900** may use any combination of electrodes to deliver therapy and/or detect electrical signals from the patient.

Therapy generation circuitry **1996** is electrically coupled to electrodes **1952**, **1956**, and/or **1960** positioned on the housing of implantable medical device **1900**. In the illustrated example, therapy generation circuitry **1996** is configured to generate and deliver electrical stimulation therapy to the heart. For example, therapy generation circuitry **1996** may deliver pulses to a portion of cardiac muscle within the heart via electrodes **1952**, **1956**, and/or **1960**. In some examples, therapy generation circuitry **1996** may deliver pacing stimulation in the form of electrical pulses. Therapy generation circuitry **1996** may include charging circuitry, and one or more charge storage devices, such as one or more capacitors. Switching circuitry (not shown) may control when the capacitor(s) are discharged to electrodes **1952** and **1960**.

Sensing circuitry **1998** monitors signals from at least one of electrodes **1952**, **1956**, and **1960** to monitor electrical activity of the heart, impedance, or another electrical phenomenon. Sensing may be done to determine heart rates or heart rate variability, or to detect ventricular dyssynchrony, arrhythmias (e.g., tachyarrhythmias) or other electrical signals. Sensing circuitry **1998** may include switching circuitry to select the electrode polarity used to sense the heart activity. In examples with more than two electrodes, processing circuitry **1990** may select the electrodes that function as sense electrodes, i.e., select the sensing configuration, via the switching circuitry within sensing circuitry **1998**. In some examples, electrode **1952** is connected to a first pole of a battery of implantable medical device **1900** (e.g., the positive terminal of the battery), electrode **1960** is connected to a second pole of the battery (e.g., the case ground), and electrode **1956** is a sense electrode configured to receive signals in the environment surrounding implantable medical device **1900**. Other configurations of electrodes **1952**, **1956**, and **1960** are also possible.

Motion sensor **1980** may be contained within the housing of implantable medical device **1900** and include one or more accelerometers, gyroscopes, electrical or magnetic field sensors, or other devices capable of detecting motion and/or position of implantable medical device **1900**. For example, motion sensor **1980** may include a three-axis accelerometer (three-dimensional accelerometer) that is configured to detect accelerations in any direction in space. Specifically, the three-axis accelerometer may be used to detect the motion of implantable medical device **1900** that may be indicative of cardiac events and/or noise.

When processing circuitry **1990** controls therapy generation circuitry **1996** to deliver ventricular pacing pulses for CRT, processing circuitry **1990** may also control motion sensor(s) **1980** to generate a signal that varies with the cardiac contraction. In some examples, motion sensor(s) **1980** may generate the signal substantially continuously. For each cardiac cycle during which a ventricular pacing pulses is delivered, processing circuitry **1990** may identify one or more features of the cardiac contraction within the signal. Processing circuitry **1990** may determine whether the contraction is a fusion beat or other type of beat, e.g., intrinsic or fully-paced, based on the one or more features.

Communication circuitry **1994** includes any suitable hardware, firmware, software or any combination thereof for communicating with another device, such as an external device or another implantable device. In some examples, communication circuitry **1994** may be configured for tissue conductive communication with another implantable medical device via electrodes **1952**, **1956**, and/or **1960**. Implantable medical device **1900** may communicate with an external device via the other implantable medical device, or communication circuitry **1994** may be configured for radiofrequency communication with an external device, e.g., via an antenna.

FIG. **20** is a flow diagram illustrating an example process for assembling an implantable medical device, in accordance with one or more aspects of this disclosure. The techniques of FIG. **20** are described with reference to implantable medical device **1400** shown in FIG. **14**, although other components may exemplify similar techniques.

In the example of FIG. **20**, a battery module including a battery, a battery header, and a feedthrough are provided within housing portion **1452**B (**2000**). The battery header is attached to the battery, where the battery header is positioned in the positive x-axis direction from the battery. The feedthrough includes a conductive material extending through battery header to provide an electrical connection through battery header. Side wall **1470** may be part of the battery header, or side wall **1470** may be separate from and attached to electric contact assembly **1486**A.

In the example of FIG. **20**, electric contact assembly **1486**A is mounted to the battery header (**2002**). Additionally or alternatively, electric contact assembly **1486**A may be mounted to side wall **1470**. Electric contact assembly **1486**A may be soldered, welded, or adhered to the battery header. The spring contacts of electric contact assembly **1486**A are connected to the battery anode and the feedthrough of the battery header (**2004**). In examples in which electric contact assembly **1486**A includes more than one spring contact, a first spring contact may be connected to the anode of the battery and a second spring contact may be connected to the cathode of the battery, which is referred to as a multiple-channel configuration. In a single-channel configuration, the first and second spring contacts may both be connected to the same pole of the battery.

In the example of FIG. **20**, housing portion **1452**A is mounted to the battery header (**2006**). Housing portion **1452**A can be mounted to the battery header and/or side wall **1470**. Electronics module **1484** is then inserted into housing portion **1452**A and comes into contact with the spring contacts of electric contact assembly **1486**A (**2008**). Electric contact assembly **1486**A forms the floor of the chamber, and electronics module **1484** is dropped into the chamber. In some examples, zero, one, or both of electric contact assemblies **1486**A and **1486**B may be permanently attached to electronics module **1484** using solder, adhesive, and/or conductive epoxy. In examples in which neither of electric contact assemblies **1486**A and **1486**B is permanently attached to electronics module **1484**, electronics module **1484** can be held in place by the pressure applied by the spring contacts of electric contact assemblies **1486**A and **1486**B.

End cap **1472** is mounted to housing portion **1452**A to push electronics module **1484** against the spring contacts of electric contact assemblies **1486**A and **1486**B (**2010**). Before mounting end cap **1472** on housing portion **1452**A, electric contact assembly **1486**B can be attached to end cap **1472**, so that the combined structure of end cap **1472** and electric contact assembly **1486**B is mounted to housing portion **1452**A. The spring contacts of electric contact assembly **1486**B may be electrically connected to an electrode of end cap **1472** by a feedthrough (e.g., a conductive path through the hermetic seal of implantable medical device **1400**). When end cap **1472** is mounted, end cap **1472** covers the top end of the chamber. The enclosure of implantable medical device **1400** may be laser welded by laser welding end cap **1472** to housing portion **1452**A. Implantable medical device **1400** may also include end cap **1458** that is laser welded to housing portion **1452**B or electrode **1460**. Electric contact assembly **1486**B may be pre-connected to end cap **1472** such that there is an electrical connection between a spring contact of electric contact assembly **1486**B and a sense electrode on end cap **1472** via a feedthrough pin. After assembly, housing portion **1452**A can be welded to the headers to seal the enclosure around electronics module **1484**.

Before end cap **1472** is mounted to housing portion **1452**A, electric contact assembly **1486**B can be attached to end cap **1472**. Then the combined structure of end cap **1472** and electric contact assembly **1486**B can be pressed against and/or permanently attached to electronics module **1484**.

FIG. **21** is a flow diagram illustrating an example process for assembling an implantable medical device with a permanent attachment on at least one electric contact assembly, in accordance with one or more aspects of this disclosure. The techniques of FIG. **21** are described with reference to implantable medical device **1400** shown in FIG. **14**, although other components may exemplify similar techniques. The techniques described with respect to the flow diagram of FIG. **21** can be implemented with only one electric contact assembly having spring contacts. For example, one end of electronics module **1484** may be pressed against an electric contact assembly having spring contacts, where the other end of electronics module **1484** is soldered to an electric contact assembly having solder bumps.

Steps **2100**, **2102**, **2104**, and **2106** shown in FIG. **21** are similar to steps **2000**, **2002**, **2004**, and **2006** shown in FIG. **20**. In the example of FIG. **21**, a battery module including a battery, a battery header, and a feedthrough are provided within housing portion **1452**B (**2100**). Electric contact assembly **1486**A is mounted to the battery header (**2102**). The spring contacts of electric contact assembly **1486**A can be connected to the battery anode and the feedthrough of the battery header (**2104**). Housing portion **1452**A is mounted to the battery header (**2106**).

Electronics module **1484** is pre-attached to electric contact assembly **1486**B, which is mounted on end cap **1472** (**2108**). Electronics module **1484** can be connected to electric contact assembly **1486**B using a solder process. Electric contact assembly **1486**B may include solder bumps similar to electric contact assembly **1586**B shown in FIG. **17**. The solder bumps of electric contact assembly **1486**B can be reflowed to form a permanent connection with electronics module **1484**. The combined structure of electronics module **1484**, electric contact assembly **1486**B, and end cap **1472** can be a pre-assembled structure that is shipped to the final manufacturing location where steps **2110** and **2112** are performed.

The combined structure of electronics module **1484** and end cap **1472** is then inserted into housing portion **1452**A (**2110**). Housing portion **1452**A can be attached to end cap **1472** by welding or using another attachment process (**2112**).

Various examples of the disclosure have been described. Any combination of the described systems, operations, or functions is contemplated. These and other examples are within the scope of the following claims.

What is claimed is:

1. An implantable medical device comprising:
- a battery;
- an electronics module electrically connected to the battery;
- an elongated housing comprising a side wall positioned between the battery and an end cap, wherein the electronics module is positioned within the elongated housing between the battery and the end cap; and
- an electrical contact assembly comprising a first spring contact and a second spring contact,
- wherein the electrical contact assembly is positioned within the elongated housing between the electronics module and the battery or is positioned within the elongated housing between the electronics module and the end cap.

2. The device of claim **1**, further comprising a battery header and an electrical feedthrough electrically connected to the battery and extending through the battery header, wherein the electrical contact assembly is positioned between the electronics module and the battery header and electrically connected to the electrical feedthrough and the electronics module.

3. The device of claim **2**, wherein the electrical contact assembly is a first electrical contact assembly, wherein the electrical feedthrough is a first electrical feedthrough, and further comprising:
- a second electrical feedthrough extending through the end cap, and
- a second electrical contact assembly comprising a third spring contact and a fourth spring contact,
- wherein the second electrical contact assembly is positioned within the housing between the electronics module and the end cap and electrically connected to the second electrical feedthrough and the electronics module, and
- wherein at least one of the first, second, third, or fourth spring contacts is permanently attached to the electronics module.

4. The device of claim **1**, wherein the electrical contact assembly further comprises an insulative backing, wherein the first and second spring contacts are mounted to the insulative backing, and wherein each of the first and second spring contacts comprises a contact arm biased away from the insulative backing.

5. The device of claim **4**, wherein each of the first and second spring contacts comprise a plurality of contact arms biased away from the insulative backing.

6. The device of claim **4**, wherein the contact arm comprises an electrically conductive plating.

7. The device of claim **4**, wherein an end of the contact arm comprises a raised contact surface.

8. The device of claim **1**, further comprising an electrical feedthrough extending through the end cap, wherein the electrical contact assembly is positioned between the electronics module and the end cap and electrically connected to the electrical feedthrough and the electronics module.

9. The device of claim **1**,
- wherein the electrical contact assembly further comprises a third spring contact and a fourth spring contact, and

wherein the first, second, third, and fourth spring contacts are pressed against the electronics module.

10. The device of claim **1**, further comprising an electrode positioned on an exterior of the device and electrically isolated from the elongated housing,

wherein the first spring contact is electrically connected to the elongated housing,

wherein the second spring contact is electrically connected to the electrode, and

wherein the first spring contact is electrically isolated from the second spring contact.

11. The device of claim **1**, further comprising an electrode positioned on an exterior of the device and electrically isolated from the elongated housing,

wherein the first spring contact is electrically connected to the second spring contact,

wherein the first spring contact is electrically connected to the electrode, and

wherein the first spring contact and the second spring contact are electrically isolated from the elongated housing.

12. The device of claim **1**, wherein the electronics module comprises one or more circuit layers oriented perpendicular to a longitudinal axis of the elongated housing.

13. The device of claim **1**, wherein the electronics module comprises a plurality of circuit layers located adjacent to each other and oriented perpendicular to a longitudinal axis of the elongated housing.

14. The device of claim **1**, wherein the electronics module comprises a circuit board oriented parallel to or along a longitudinal axis of the elongated housing.

15. The device of claim **1**, wherein when assembled, at least one of the first spring contact or the second spring contact applies pressure in a direction parallel to a longitudinal axis of the housing and toward the electronics module.

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